Geoindicators Scoping Report for Waterton-Glacier International Peace Park

Strategic Planning Goal Ib4

August 20-22, 2002
West Glacier, Montana

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Scoping Summary

Introduction

The National Park Service, Parks Canada, U.S. Geological Survey, and International Union of Geological Sciences sponsored a geoindicators scoping meeting in Waterton-Glacier International Peace Park in West Glacier, Montana on August 20-22, 2002.

Purpose of meeting

The purpose of the meeting was threefold: (1) to identify significant geological processes and features that are part of the park's ecosystem, (2) to evaluate human influences on those processes and features, and (3) to provide recommendations for studies to support resource management decisions, geologic inventory and monitoring projects, and research to fill data gaps. The scoping meeting was designed to use the participants' expertise and institutional knowledge and build on the synergy of the participants through field observations, group discussion, and the exchange of ideas.

Government Performance and Results Act (GPRA) Goal Ib4

This meeting satisfies the requirements of the GPRA Goal Ib4, which is a knowledge-based goal that states, "Geological processes in 53 parks [20% of 265 parks] are inventoried and human influences that affect those processes are identified." The goal was designed to improve park managers' capabilities to make informed, science-based decisions with regards to geologic resources. It is the intention of the goal to be the first step in a process that will eventually lead to the mitigation or elimination of human activities that severely impact geologic processes, harm geologic features, or cause critical imbalance in the ecosystem.

Because GPRA Goal Ib4 inventories only a sampling of parks, information gathered at Waterton-Glacier International Peace Park may be used to represent other parks with similar resources or human influences on those resources, especially when findings are evaluated for Servicewide implications.

Geoindicator background information

A Working Group of the International Union of Geological Sciences developed geoindicators as an approach for identifying rapid changes in the natural environment. The National Park Service uses geoindicators during scoping meetings as a tool to fulfill GPRA Goal Ib4. Geoindicators are measurable, quantifiable tools for assessing rapid changes in earth system processes. Geoindicators evaluate 27 earth system processes and phenomena (Appendix A) that may undergo significant change in magnitude, frequency, trend, or rates over periods of 100 years or less and may be affected by human actions (Appendix B). Geoindicators are used as a framework to guide the discussion and field observations during scoping meetings (Appendix C). The geoindicators scoping process for the National Park Service was developed to help determine the studies necessary to answer management questions about what is happening to the environment, why it is happening, and whether it is significant.

The health and stability of an ecosystem is evaluated during the geoindicatiors scoping process. The geologic resources of a park—soils, caves, streams, springs, beaches, volcanoes, etc.—provide the physical foundation required to sustain the biological system. Geological processes create topographic highs and lows; affect water and soil chemistries; influence soil fertility, hillslope stability, and the flow styles of surface water and groundwater. These factors, in turn, determine where and when biological processes occur, such as the timing of species reproduction, the distribution of habitats, the productivity and type of vegetation, and the response of ecosystems to human impacts (Appendix D).

Park selection

The idea to hold a geoindicators scoping meeting in Waterton-Glacier International Peace Park developed at the "International Workshop on Geoindicators for Ecosystem Monitoring in Parks and Protected Areas" in Gros Morne National Park, Newfoundland, Canada on September 10-14, 2001. The desire for continued collaboration between the National Park Service and Parks Canada, in particular, made hosting a meeting in the Peace Park an ideal location. In addition the park was selected for is its unique geologic resources (Appendix E), park setting (Appendix F), and human use.

Summary of Results

During the scoping meeting, geoindicators appropriate to Waterton-Glacier International Peace Park were addressed. Of the 27 geoindicators, 21 were recognized as on-going processes in the park. The issues surrounding each geoindicator were identified, and participants rated the geoindicator with respect to the importance to the ecosystem and human influence (Geoindicator table). The park staff rated the significance for park management. A compilation of the notes taken during the scoping session (Appendix G) and field trip (Appendix H) are included with the report. These notes highlight additional information regarding geoindicators that may be useful to park managers.

Geoindicator table for Waterton-Glacier International Peace Park

GEOINDICATOR	Importance to park ecosystem	Human influence on geology	Significance for natural resource management
AEOLIAN			
Dust storm magnitude, duration, and frequency	2	1	1
Wind erosion (transport and deposition)	3	3	4
GLACIAL & PERIGLACIAL			
Frozen ground activity	2	1	1
Glacier fluctuations	4	N/A	2
GROUNDWATER			
Groundwater chemistry in the unsaturated zone	1	1 (3 locally)	3
Groundwater quality	4	1 (5 locally)	3
Groundwater level	4	1	2
SURFACE WATER			
Lake levels and salinity (including lake ice)	2	1	3
Stream channel morphology	4	2 (4 locally)	4
Stream sediment storage and load	4	2 (4 locally)	4
Streamflow	5	1	3
Surface water quality	5	1 (5 locally)	3
Wetlands extent, structure, hydrology	5	2 (4 locally)	5
SOILS			
Soil quality	5	2 (4 locally)	5
Soil and sediment erosion	5	2 (4 locally)	5
TECTONICS & GRAVITY			
Seismicity	1	N/A	1
Slope failure	4	1	5
Snow avalanches	5	1	5
OTHER			
Karst activity	1	U	2
*Sediment sequence and composition	5*	5*	5*
Subsurface temperature regime	U	U	U
N/A - Not Applicable 1 - LOW or no substantial influence on, or utility for 3 - MODERATELY influenced by, or has some utility for 5 - HIGHLY influenced by, or with important utility for U - Unknown; may require study to determine applicability	*Sediment sequences and composition is a tool with great significance for enhancing the information base of the park's ecosystem, identifying human influences on the ecosystem, and providing data for management decisions and planning.		

Significant geoindicators

Geoindicators with importance to park ecosystem

Snow Avalanches
Snow avalanches are ubiquitous throughout the park; they are a major landscape disturbance that shapes the park's ecosystem. Snow-avalanche tracks have great importance to the ecosystem; they are: productive environments, key habitat that serve as migration paths for grizzly and mountain goats, fuel breaks for fire, conduits for carbon and sediment from higher to lower elevations, including streams.

Soil and sediment erosion
Soil erosion is part of the natural system in Waterton-Glacier International Peace Park. Concerns arise for ecosystem health when effects of soil and sediment erosion are human-caused and detrimental, such as soil erosion resulting from poor design and construction of facilities and infrastructure. Estimates of soil erosion are essential to issues of land and water management and to ecosystem health and function.

Soil quality
Concerns regarding soil quality in the park include: breakdown of soil structure, loss of function, harm to soil biota, regional acid deposition, nitrate deposition (from urban pollution and fertilizers), and airborne-mercury deposition from power plant emissions.

Streamflow
Streamflow affects riparian zones and wetlands in the park. Streamflow directly reflects climatic variation. Stream systems play a key role in the regulation and maintenance of biodiversity. Changes in streams and streamflow are indicators of changes in basin dynamics and land use.

Surface water quality
In addition to being a public health issue, surface water quality is an essential component of ecosystem health. All forms of life depend on clean water. Waterton-Glacier International Peace Park sits at the headwaters of the Waterton and Belly rivers. Since water quality exceeds standards, the surface water quality geoindicator is a good indicator of change, and minor changes are easily detectable.

Wetlands extent, structure, and hydrology
Waterton-Glacier International Peace Park has many different kinds of wetlands, including fens, bogs, nutrified lakes, and swamps. Glacial retreat has influenced wetlands. Wetlands in the park are extremely dynamic, and nearly all species of wildlife rely on wetlands in one way or another.

Geoindicators with significant human influences

It is important to note that 95% of Glacier National Park is proposed wilderness, and over 80% of Waterton Lakes National Park has been recommended for wilderness declaration. The remaining small percentage of land—that is, the developed corridors along the Going-to-the-Sun Road, all roads and part of Blakiston Fan in Waterton Lakes, and established townsites—is where park staff focuses much of their energy and resources on managing the effects of human activities.

Groundwater quality
Management concerns revolve around human influences on groundwater quality, such as the effects of sewage treatment, inholders' septic systems, salt application to roads (in Waterton Lakes National Park only), road runoff, pesticides, gasoline leaks from underground storage tanks (e.g., in Apgar), and service stations in the park.

Surface water quality
Human practices that affect surface water quality include herbicide and pesticide applications, e.g., for eradicating knapweed. Locations of campgrounds, lodges, roads, and other facilities and infrastructure in sensitive floodplain and stream delta areas have produced runoff that impacts fragile invertebrate communities in streams. Localized situations, such as boating on St. Mary Lake and Upper and Middle Waterton Lake, have resulted in diesel fuel spills. For instance, during a high wind event, a barge capsized on St. Mary Lake spilling 50 gallons of diesel fuel.

Geoindicators with management significance

Snow avalanches
Snow avalanches are a public safety issue, particularly for winter backcountry users. Park staff spends a considerable amount of time forecasting snow avalanches. Snow-avalanche hazards are a factor in determining the opening date of the Going-to-the-Sun Road and may influence the clearing of Akamina Parkway through the winter months. Snow avalanches are also significant to management as creators of wildlife habitat, particularly grizzly bear, a threatened species in the United States.

Slope failure
Slumping along Many Glacier Road is a continuing maintenance issue. Not only does the road undercut the slope, but water from adjacent Lake Sherburne saturates and weakens the slope. Slumping along Blakiston Creek is a concern along parts of the Red Rock Parkway. Also, a pending question with respect to climate change and slope failure is whether increased rainfall events will cause more landslides.

Soil and sediment erosion
Management issues include construction projects that result in pulses of sediment carried downstream. For example, sediment resulting from the construction of the Going-to-the-Sun Road can be seen in the sediment column in McDonald Creek and in Lake McDonald. Reclamation of soils degraded by human actions is of high management significance.

Soil quality
Park managers spend time and resources dealing with soil quality and restoration issues, particularly because of the human impacts in developed areas, such as social trails and trail maintenance; borrow pits (historically became garbage pits, which attracted bears); horse use (primarily a legacy issue); popular lakes with multiple entry points; locating and constructing park facilities, e.g., Logan Pass Visitor Center; depletion of soils along roadsides, which causes

greater amount of noxious weeds; plowing which causes soil compaction and depletion along roadsides; and salt and petrochemical runoff from roads.

Wetlands extent, structure, and hydrology
In the United States, law mandates that land managers always consider wetlands in management decisions. In Canada, it is not legally mandated, but managers recognize the significance of wetlands and the potential impact of human uses on them.

Sediment sequence and composition
One geoindicator in particular was singled out and warrants mention. Unlike the other geoindicators, sediment sequence and composition is not a geological process, but rather a tool with great significance for enhancing the information base of the park's ecosystem, identifying human influences on the ecosystem, and providing data for resource management decisions and planning. It provides the necessary background information and a past context of both natural processes and human activities. The chemical, physical, and biological character of aquatic sediments can provide a finely resolvable record of environmental change, in which natural events may be clearly distinguished from human inputs.

Summary of Recommendations

The following summary of recommendations lists ideas that were discussed during the August 20-22, 2002 scoping meeting held in Waterton-Glacier International Peace Park. The summary includes recommendations for inventory and monitoring, as well as research. Recommendations are not listed in any order of priority.

Recommendations for inventory and monitoring

1. Inventory and monitor wetlands
There are many different kinds of wetlands in the park: fens, bogs, nutrified lakes, swamps, etc. Park managers need more accurate and consistent descriptions of these wetlands. The first step toward an inventory would be to validate the classification of the Fish and Wildlife Service and refine its delineation. Once sites have been identified, historical aerial photographs (in sequence) followed by ground-truthing could be used to verify and characterize the sites. The inventory could be supplemented by remote sensing, although remote sensing can be expensive and the tree canopy may hide some wetlands.

Monitoring is needed to determine future changes in wetlands. If significant changes are detected, then research will be required to determine the cause(s). Monitoring of wetlands could be multi-faceted, including vascular plants and water chemistry. Wetland studies suggest opportunities for integrated research and collaboration. Paleoecological methods can be used to date peat and/or sediments to determine the hydrological succession of wetlands.

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2. Provide groundwater data to Montana Bureau of Mines and Geology
The Montana Bureau of Mines and Geology has a statewide groundwater program. Park staff is welcome to share/submit data to Montana Bureau of Mines and Geology for entry into the Bureau's Ground-Water Information Center (GWIC) database. Information in the database is available via the Bureau's GWIC Web site at http://mbmggwic.mtech.edu/. High mountain areas, such as those in the park, typically do not have many wells, so information for these areas is limited.

Contact
- Tom Patton, Manager, Ground Water Assessment Program, 406-496-4153, tpatton@mtech.edu or directly access the database

3. Verify soil survey
Both Waterton Lakes National Park and Glacier National Park have soil surveys but need a consistent interpretation of soil classification, derivative products, and sampling to characterize locales (e.g., along road corridors).

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4. Monitor change in soil carbon storage
Participants recommend that park managers monitor changes in carbon storage once every 5 to 10 years, by measuring the organic carbon in surface soil layer(s) through sampling and then resampling at the same locations. The use of Douglas fir, which is very sensitive to CO_2, can be used as an indicator species and as an early warning of detrimental changes in the ecosystem. See Appendix I for corresponding proposal.

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References
Thompson, R.S., Hostetler, S.W., Bartlein, P.J., and Anderson, K.H., 1998, A strategy for assessing potential future changes in climate, hydrology, and vegetation in the western United States: U.S. Geological Survey Circular 1153, 20 p.

White, J.D., Running, S.W., Thornton, P.E., Keane, R.E., Ryan, K.C., Fagre, D.B., and Key, C.H., 1998, Assessing simulated ecosystem processes for climate variability at Glacier National Park, USA: Ecological Applications, v. 8, no. 3, p. 805-823.

White, J.D. and Running, S.W., 1994, Testing scale-dependent assumptions in regional ecosystem simulations: Journal of Vegetation Science, v. 5, no. 5, p. 687-702.

Sources of information on the Web
http://www.forestry.umt.edu/ntsg/
Web site of work done by Steve Running on carbon and climate change

5. Monitor streamflow and seek secure funding
The park needs basic monitoring of streamflow in the interior of park. Secure funding is needed. Participants recommend that park managers pursue a partnership with U.S. Geological Survey. The NPS Water Resources Division can assist with defining needs including monitoring locations, number of monitoring stations needed, and cost. Redwood National and State Park has an established partnership with U.S. Geological Survey for monitoring gauging stations and could serve as a model.

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6. Repeat survey of lakes
A survey of baseline water quality data for lakes needs to be repeated.

Contact
- Dan Fagre, 406-888-7922, dan_fagre@usgs.gov

7. Use aerial photography to document changes and features in the landscape
Use repeat aerial photography to document the change in snow-avalanche paths (extent, location) over time and document features caused by slope failure. Scan past aerial photographs, contained in park archives, to use for analysis and interpretation of future slope failure in a digital format.

8. Add seismic station(s) within park boundary
A seismic monitoring program run by Montana Bureau of Mines and Geology (MBMG) currently has 34 stations, mostly in the western part of Montana. Additionally, they receive data from stations in bordering areas, including a station in Waterton Lakes National Park. The latter, in conjunction with other stations that they operate, allows MBMG to locate earthquakes in the vicinity of the park, but resolution is poor and the smaller earthquakes go undetected. Much better detection and resolution could be obtained with 1 or 2 additional stations inside the park. MBMG data feed into the national U.S. Geological Survey system in Colorado. Detected quakes are automatically analyzed and information is posted on MBMG's Web site within minutes: http://mbmgquake.mtech.edu/. Each station costs $15,000-$25,000 plus nominal upkeep of the station.

Contact
- Mike Stickney, Manager, Earthquake Studies Office, 406-496-4332, mstickney@mtech.edu

9. Monitor dust storms as part of air quality monitoring

Dust storms may be a factor in the decline of air quality and visibility in Waterton-Glacier International Peace Park. If air quality declines, an analysis of particles (size and composition) would help determine source area(s). It would assist in answering the question, What impact are western Washington's agricultural practices having on the park? This type of data collection is being conducted in Olympic National Park.

10. Inventory cave resources
Park managers in Glacier National Park have basic information, e.g., number and location, about the significant caves within its boundaries, but do not have information on cave resources or whether conditions within the caves are changing. Local cavers could be used to perform an inventory, specifically there is a "grotto" (cavers group of the National Speleological Society) in Missoula. Such groups have the necessary expertise to perform such an inventory and have been known to provide this service for free.

Contact
- Ron Kerbo, Cave Specialist, NPS Geologic Resources Division, 303-969-2097, ron_kerbo@nps.gov

11. Study wind erosion on an ecosystem-wide scale
How significant overall is the wind as an erosion-causing agent? What ecosystem-wide impact does wind erosion have? In order to answer these questions, wind erosion would need to be identified and separated from impacts caused by other forms of erosion, including human-caused erosion. Once these impacts are identified, site-specific inventories could be performed using repeat photography and GPS surveys.

12. Inventory stream channels
Natural Resources Conservation Service (NRCS) in Montana is photographing stream reaches using digital video camcorder (with GPS and Red Hen software systems). The effort was initiated for fisheries and riparian management, but information could be extrapolated and used for stream channel morphology and stream sediment storage and load.

Contact
- Tom Pick, tpick@mt.nrcs.usda.gov

13. Monitor mass balance of glaciers
Knowledge of seasonal mass balances (e.g., summer and winter) would shed light on glacier fluctuations in Waterton-Glacier International Peace Park. For example, it would help answer questions such as: Is glacier contraction caused primarily by less nourishment in winter or by more melt in summer? Monitoring of mass balance would also assist in the interpretation of streamflow records.

Having a glacier mass balance site at the longitude of Waterton-Glacier International Peace Park would make an excellent contribution to the Global Terrestrial Network-Glacier (GTN-G) of World Meteorological Organization's (WMO) Global Climate Observing Network (GCOS). A site this far south may provide a good analog for what could be expected further north in the Canadian Rocky Mountains over the next century with respect to global climate change. In addition, Waterton-Glacier International Peace Park could be part of the Global Terrestrial Observing Systems (GTOS), Terrestrial Monitoring System (TEMS).

Contact

- Michael N. Demuth, 613-996-0235, mdemuth@nrcan.gc.ca

Recommendations for research

1. Create "lake ice model"

Information about lake ice (annual first thaw and first freeze) would provide data regarding climate change and serve as an early-warning indicator of change. It is also significant for the arrival of migrating waterfowl. Creating a "lake ice model" could be done using existing meteorological data and information from past issues of the Hungry Horse newspaper, which records years that the large lakes in the area have frozen over.

Contact

- Dan Fagre, 406-888-7922, dan_fagre@usgs.gov

2. Determine whether small lakes are being filled in with sediment

Radiometric dating techniques could be used to address the question of whether the small lakes in the park are being filled in with sediment.

Contact

- Marlow Pellatt, 604-666-2556, Marlow_Pellatt@pc.gc.ca

3. Update surficial geologic map

The surficial geologic map of Glacier National Park needs to be updated. The current map does not show all of the locations of snow-avalanche paths, all the areas of landsliding, or all the lake deposits. A coordinated mapping effort between Glacier National Park and Waterton Lakes National Park is recommended for consistency across the Canadian-United States boundary. Once this map is updated, a derivative map that shows landslide-hazard areas could be produced that would provide needed information to park managers.

Reference

Carrara, P.E., 1990, Surficial geologic map of Glacier National Park, Montana: U.S. Geological Survey Miscellaneous Investigation Series, No. I-1508-D, 1:100,000.

4. Conduct snow-avalanche studies

The significance of snow avalanches on the park's ecosystem and for park management was discussed previously. Having more information regarding the frequency, cycles, and locations of snow avalanches would be useful to park managers. Park managers are encouraged to seek funding through the NPS Geoscientist-in-the-Parks program. Possible projects include:

- Develop frequency of event analysis and historical record (e.g., from Waterton townsite record). Some attempt as this has been made using tree rings.
- Compare east and west side cycles of snow avalanches.

- Establish landscape-level disturbance agent and look at drivers. Check against Pacific Decadal Oscillation climatic variations and see if it is tied to the response of snow avalanches.
- Answer questions such as, Does snowfall level influence frequency? How much woody debris do snow avalanches deliver to the Highway 2 corridor? What is the relative amount of woody debris vs. rock material in snow avalanches?

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5. Answer research questions regarding slope failure
What is the relative importance of mass movement vs. stream transport? Will an increase in rain events cause more landslides?

Reference
Rapp, A., 1960, Recent development of mountain slopes in Karkevagge and surrounding northern Scandinavia: Geografisk Annaler, v. 42, p. 73-200.

6. Answer research questions regarding wetlands
What is the effect of fire on wetlands? Where and to what extent do wetlands exist from year to year? What are past impacts of glacier fluctuations on wetlands?

References
Hansen, H.P., 1948, Postglacial forests of the Glacier National Park region: Ecology, v. 29, p. 146-152.

Elias, S.A., 1988, Climatic significance of Late Pleistocene insect fossils from Marias Pass, Montana: Canadian Journal of Earth Sciences, v. 25, p. 922-926.

Carrara, P.E., 1995, A 12,000 year radiocarbon date of deglaciation from the Continental Divide of northwestern Montana: Canadian Journal of Earth Sciences, v. 32, p. 1203-1307.

Carrara, P.E., 1989, Late Quaternary glacial and vegetative history of the Glacier National Park region, Montana: U. S. Geological Survey Bulletin 1902, 64 p.

Other recommendation

Recommend that the Vital Signs Network hire a soil scientist
Many of the natural resources staff members in Glacier National Park have strong backgrounds in plant ecology and work with the Natural Resource Conservation Service (NRCS). However, there is a need for expertise in soil science. Hiring a soil scientist would be extremely difficult at the park-level because of budgetary constraints, so the participants suggest that park staff encourage the Rocky Mountain Vital Signs Network to hire a soil scientist that could be shared with the other parks in the network.

List of Participants

Glacier National Park

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Appendices

Appendix A: Descriptions of 27 Geoindicators
Appendix B: Human Influences
Appendix C: Introducing Geoindicators
Appendix D: Species Don't Stand Alone—Geology's Role in Ecosystems
Appendix E: Park Geological Setting
Appendix F: Park Setting
Appendix G: Compilation of notes taken during Scoping Session
Appendix H: Compilation of notes taken during Field Trip
Appendix I: Proposal for Soil Carbon Storage Study

Appendix A: Description of 27 Geoindicators

Geoindicators have been developed as tools to assist in integrated assessments of ecosystems, as well as for environmental reporting. As descriptors of common earth processes that operate in a variety of settings, geoindicators represent collectively a new kind of landscape metric, one that concentrates on the non-living components of the lithosphere, pedosphere, and hydrosphere, and their interactions with the atmosphere and biosphere (including humans).

The Geoindicator Checklist: Geoindicators are available in the form of a checklist that identifies 27 earth system processes and phenomena that are liable to change in less than a century in magnitude, direction, or rate to an extent that may be significant for environmental sustainability and ecological health.

The 27 geoindicators are:

1. Coral chemistry and growth patterns
2. Desert surface crusts and fissures
3. Dune formation and reactivation
4. Dust storm magnitude, duration, and frequency
5. Frozen ground activity
6. Glacier fluctuations
7. Groundwater quality
8. Groundwater chemistry in the unsaturated zone
9. Groundwater level
10. Karst activity
11. Lake levels and salinity
12. Relative sea level
13. Sediment sequence and composition
14. Seismicity
15. Shoreline position
16. Slope failure (landslides)
17. Soil and sediment erosion
18. Soil quality
19. Streamflow
20. Stream channel morphology
21. Stream sediment storage and load
22. Subsurface temperature regime
23. Surface displacement
24. Surface water quality
25. Volcanic unrest
26. Wetlands extent, structure, hydrology
27. Wind erosion

The descriptions of geoindicators that follow were adapted from the geoindicators checklist developed by the International Union of Geological Sciences through its Commission on Geological Sciences for Environmental Planning. Each geoindicator includes a brief description, reasons for its significance to an ecosystem, and examples of human influences from national park settings (when available). The National Park Service uses these descriptions to facilitate discussion during scoping meetings in national parks. The purpose of a scoping meeting is to identify significant geological processes in a park's ecosystem and determine if those processes are being affected by human activities. For each scoping meeting, geoindicators are selected from the list of 27, as appropriate to the terrain and environmental issues under consideration.

Coral chemistry and growth patterns

Brief Description: Corals can be used to monitor environmental changes in the oceans and nearby coastal zone. The health, diversity, and extent of corals, and the geochemical makeup of their skeletons, record a variety of changes in the ocean surface water. These include temperature, salinity, fertility, insolation, precipitation, winds, sea levels, storm incidence, river runoff, and human inputs. Corals in coastal waters are susceptible to rapid changes in salinity and suspended matter concentrations and may be valuable indicators of the marine dispersion of agricultural, urban, mining, and industrial pollutants through river systems, as well as the history of contamination from coastal settlements.

Significance: The combination of abundant geochemical tracers, sub-annual time resolution, near-perfect dating capacity, and applicability to both current and past climatic changes establishes corals as one of the richest natural environmental recorders and archives.

Human influence: Corals respond to both natural changes in the marine environment and to anthropogenic pollution.

Desert surface crusts and fissures

Brief Description: The appearance or disappearance of thin (mm to cm) surface crusts in playas and depressions in arid and semi-arid regions may indicate changes in aridity. The formation of persistent deep, polygonal cracks in the mud and silt floors of closed basins and depressions may indicate the onset of aridification or severe drought. Surfaces may contain other desiccation features such as sedimentary dikes, evaporite deposits (especially gypsum and halite), adhesion ripples, and large salt polygons.

Physical soil crusts (thin layer with reduced porosity and increases density at the surface of the soil) and biological soil crusts (a living community of lichen, cyanobacteria, algae, and moss growing on the soil surface and binding it together) are also significant indicators of the state of an ecosystem. Recovery of biological crusts may take decades to hundreds of years. The amount and extent of degration to soil crusts are excellent indicators of physical disturbance to an area.

Significance: Desert surface crusts are important because they protect the underlying fine material from wind erosion. Physical and biological crusts; in Canyonlands and Arches national parks, for instance; generally help to control wind erosion. Biological crusts fix atmospheric nitrogen for vascular plants; provide carbon to the interspaces between vegetation; secrete metals that stimulate plant growth; capture dust (i.e., nutrients) on their rough, wet surface areas; and decrease surface albedo. Depending on soil characteristics, biological crusts may increase or reduce the rate of water infiltration. By increasing surface roughness, they reduce runoff, thus increasing infiltration and the amount of water stored for plant use.

Human Influences: The formation of surface crusts is related primarily to natural causes, but hydrological regimes that affect crust formation and persistence may be altered by human activities, such as river diversion and groundwater extraction. Both physical and biological crusts can be affected by physical disturbances caused by wheeled or tracked vehicles, livestock hooves, and hiking and cycling. The impact is determined by the severity, frequency, and timing of the disturbance and by the size of the disturbed area.

In Arches National Park, grazing practices have impacted physical and biological crusts. Seventy-five percent of the park was grazed until 1974, and cow trespass still occurs. Soil and nutrient cycles have not recovered from this past practice (2002). Trampling by visitors at North and South Window Arch, to "get the perfect picture" or to short-cut to the parking lot, has damaged soil crusts in the area. On the boundary of Arches and Canyonlands national parks, the use of seismic "thumper" trucks during oil and gas exploration created 160 miles of roads and 110 miles of ATV tracks—all of which damaged soil crusts in the area.

Dune formation and reactivation

Brief Description: Dunes and sand sheets develop under a range of climatic and environmental controls, including wind speed and direction, and moisture and sediment availability. In the case of coastal dunes, sea-level change and beach and nearshore conditions are important factors. Organized dune systems and sheets in continental environments form from sediment transported or remobilized by wind action. New generations of dunes may form from sediment remobilized by climatic change and/or human disturbances.

Sand movement is inhibited by moisture and vegetation cover, so that dunes can also be used as an indicator of near-surface moisture conditions. Changes in dune morphology or position may indicate variations in aridity (drought cycles), wind velocity and direction [see wind erosion], or disturbance by humans.

Significance: Moving dunes may engulf houses, fields, settlements, and transportation corridors. Active dunes in sub-humid to semi-arid regions decrease arable land for grazing and agriculture. They also provide a good index of changes in aridity. Coastal dunes are important determinants of coastal stability, supplying, storing, and receiving sand blown from adjacent beaches. Dunes play an important role in many ecosystems (boreal, semi-arid, desert, coastal) by providing morphological and hydrological controls on biological gradients.

Human Influence: Widespread changes can be induced by human disturbance, such as alteration of beach processes and sediment budgets, destruction of vegetation cover by trampling or vehicle use, overgrazing, and the introduction of exotic species.

Sleeping Bear Dunes National Seashore has a number of prominent dunes (300-400 ft high): Sleeping Bear Dune, Empire Dunes, Pyramid Dunes, Michigan Overlook, and the Dune Climb. Most of these dunes are perched dunes and consist of a relatively thin blanket of sand that has been blown to the top of thick glacial deposits. Foot traffic and social trails have highly modified the Dune Climb and Michigan Overlook, very popular visitor sites. The Dune Climb, once a perched dune, has evolved and migrated off the plateau onto the adjacent lowland.

In Cape Cod National Seashore, migration of the dunes has caused alarm since the 19th century. Dunes have migrated into Pilgrim Lake, over homes in Provincetown, and onto roads. In the 1980s, mitigation efforts were seen as a top priority, and funding was spent on efforts such as pouring asphalt onto the dunes and revegetating the dunes.

Dust storm magnitude, duration, and frequency

Brief Description: The frequency, duration, and magnitude (intensity) of dust storms are gauges of the transport of dust and other fine sediments in arid and semi-arid regions [see wind erosion]. Desert winds carry more fine sediment than any other geological agent. An increased flux of dust has been correlated with periods of drier and/or windier climates in arid regions, historically and from proxy records in ocean and ice cores.

Significance: Local, regional, and global weather patterns can be strongly influenced by accumulations of dust in the atmosphere. Dust storms remove large quantities of surface sediments and topsoil with nutrients and seeds. Wind-borne dust, especially where the grain size is less than 10 µm, and salts are known hazards to human health. Dust storms are also an important source of nutrients for soils in desert margin areas.

Human Influence: Dust storms are natural events, but the amount of sediment available for transport may be related to surface disturbances such as overgrazing, ploughing, or removal of vegetation. Identified as single events on the scale of days in Arches and Canyonlands national parks, dust storms cause hazardous travel conditions. In addition, dust storms transport contaminated sediment from the Atlas Mine tailings pile (outside park boundary) into the employee housing area in Arches National Park.

Frozen ground activity

Brief Description: In permafrost and other cryogenic (periglacial) areas and in temperate regions where there is extensive seasonal freezing and thawing of soils, a wide range of processes lead to a variety of surface expressions, many of which have profound effects on human structures and settlements, as well as on ecosystems.

These sensitive periglacial features are found around glaciers, in high mountains (even at low-latitudes) and throughout polar regions. The development (aggradation) or degradation of permafrost is a sensitive and early indicator of climate change [see subsurface temperature regime].

Important geological parameters related to permafrost regions include:

1. **Thickness of the active layer**, the zone of annual freezing and thawing above permafrost, determines not only the overall strength of the ground but also many of the physical and biological processes that take place in periglacial terrains. Soil moisture and temperature, lithology, and landscape morphology exercise important controls on active layer thickness. Soil moisture and temperature depend largely on climatic factors, so that if the mean annual air temperature rises several degrees Celsius, the thickness of the active layer may change over time periods of years to decades.
2. **Frost heaving** is a basic physical process associated both with near surface winter freezing and with deeper permafrost aggradation. Frost heaving can displace buildings, roads, pipelines, drainage systems, and other structures. Many frozen soils have a much greater water content than their dry equivalents and undergo a local 10-20% expansion in soil volume during freezing. The frost heave process and the consequences of thawing are of great importance in the development of many of the unique features of cold terrains, including perennial hummocks and seasonal mounds, patterned ground, palsas, and pingos.
3. **Frost cracks** are steep fractures formed by thermal contraction in rock or frozen ground with substantial ice content. They commonly intersect to create polygonal patterns, which may

lead to the formation of wedges of ice and surficial material. The frequency of cracking is linked to the intensity of winter cold. Where climate is warming, ice-wedge casts replace ice wedges over periods of decades.

4. **Icings** are sheetlike masses of layered ice formed on the ground surface, or on river or lake ice, by freezing successive flows of water that may seep from the ground, flow from a spring or emerge from below river or lake ice through fractures. The intensity of icings in the southern portions of the permafrost zone may change annually, increasing with colder winters and lower snow cover combined with autumnal precipitation. Further north, icings increase in size but decrease in number when the climate cools, and vice-versa when it warms.
5. **Thermoerosion** refers to erosion by water combined with its thermal effect on frozen ground. Small channels can develop into gullies up to several kilometers in length, growing at rates of 10-20 m/yr, and in sandy deposits, as fast as 1 m/hr. The main climatic factors controlling the intensity of thermoerosion are snow-melt regime and summer precipitation.
6. **Thermokarst** refers to a range of features formed in areas of low relief when permafrost with excess ice thaws. These are unevenly distributed and include hummocks and mounds, water-filled depressions, "drunken" forests, mud flows on sloping ground, new fens, and other forms of thaw settlement that account for many of the geotechnical and engineering problems encountered in periglacial landscapes. Even where repeated ground freezing takes place, thermokarst features, once formed, are likely to persist.
7. Permafrost terrains are characterized by a wide range of slow downslope movements involving **creep**, such as rock glaciers and gelifluction, and by more rapid landslides and snow avalanches [see slope failure].

Significance: Permafrost influences natural and managed ecosystems, including forests, grasslands and rangelands, mountains and wetlands, and their hydrological systems. It is an agent of environmental change that affects ecosystems and human settlements. Permafrost may enhance further (global) climate change by the release of carbon and other greenhouse gases during thawing. Permafrost can result in serious and costly disruptions from ground subsidence, slope failure, icings, and other cryogenic processes.

Human Influence: The freezing and thawing of soils and surficial materials and the consequent ground changes are natural processes controlled by climatic conditions, and can be modified by human actions in and around settlements and engineering works.

Frozen ground activity (frost heave and gelifluction) is a major geologic process active in Rocky Mountain National Park. Patterned ground (e.g., stone polygons and stone stripe features) occurs in high alpine areas. These features are thought to form from frost heave and frost cracking and are extremely sensitive to human disturbance. Visitors have access to patterned ground along the "Tundra World Nature Trail." There is limited parking in this area, which may cut down on the number of visitors who access the patterned ground. Furthermore, visitors are asked to fan out when walking across these surfaces to minimize disturbance of these features.

<u>Glacier fluctuations</u>

Brief Description: Changes in glacier movement, length, and volume can exert profound effects on the surrounding environment, for example through sudden melting which can generate catastrophic floods, or surges that trigger rapid advances. Twice in the last hundred years the

Muldrow Glacier in Denali National Park and Preserve has “surged” flowing over lower stagnant ice and making a jumble of broken ice-blocks. Movement along the fault may trigger a surge.

Standard parameters include mass balance and the glacier length, which determines the position of the terminus. The location of the terminus and lateral margins of ice exerts a powerful influence on nearby physical and biological processes. Through a combination of specific balance, cumulative specific balance, accumulation area ratio, and equilibrium-line altitude, mass balance reflects the annual difference between net gains (accumulation) and losses (ablation). It may also be important to track changes in the discharge of water from the glacier as indicators of glacier hydrology. Abrupt changes may warn of impending acceleration in melting, cavitation, or destructive flooding.

Significance: Glaciers are highly sensitive, natural, large-scale, representative indicators of the energy balance at Earth’s surface in polar regions and high altitudes. Their capacity to store water for extended periods exerts significant control on the surface water cycle. The advance and retreat of mountain glaciers creates hazards to nearby human structures and communities through avalanches, slope failure, catastrophic outburst floods from ice and moraine-dammed lakes. Notwithstanding local glacier advances, the length of mountain glaciers and their ice volume have decreased throughout the world during the past century or two, providing strong evidence for (global) climate warming, though there may also be local correlations with decreasing precipitation.

Human Influence: Glaciers grow or diminish in response to natural climatic fluctuations. They record annual and long-term changes and are practically undisturbed by direct human actions.

Groundwater quality

Brief Description: The chemistry (quality) of groundwater reflects inputs from the atmosphere, from soil and water-rock reactions (weathering), as well as from pollutant sources such as mining, land clearance, agriculture, acid precipitation, and domestic and industrial wastes. The relatively slow movement of water through the ground means that residence times in groundwaters are generally orders of magnitude longer than in surface waters.

As in the case of surface water quality, it is difficult to simplify to a few parameters. However, in the context of geoindicators, a selection has been made of a few important first-order and second-order parameters that can be used in most circumstances to assess significant processes or trends at a time-scale of 50-100 years. The following first order indicators (in **bold**) of change are proposed, in association with a number of processes and problems, and supported by a number of second order parameters:

1. Salinity: **Cl**, SEC (specific electrical conductance), SO_4, Br, TDS (total dissolved solids), Mg/Ca, $\delta^{18}O$, $\delta^{2}H$, F
2. Acidity & Redox Status: **pH, HCO_3, Eh**, DO, Fe, As
3. Radioactivity: **^{3}H**, ^{36}Cl, ^{222}Rn
4. Agricultural Pollution: **NO_3**, SO_4, DOC (dissolved organic carbon), K/Na, P, pesticides and herbicides
5. Mining Pollution: **SO_4, pH**, Fe, As, other metals, F, Sr
6. Urban Pollution: **Cl, HCO_3, DOC**, B, hydrocarbons, organic solvents

During development and use of an aquifer, changes may occur in the natural baseline chemistry that may be beneficial or detrimental to health (e.g., increase in F, As); these should be included in monitoring programs. The quality of shallow groundwater may also be affected by landslides, fires, and other surface processes that increase or decrease infiltration or that expose or blanket rock and soil surfaces which interact with downward-moving surface water.

Significance: Groundwater is important for human consumption on a global scale, and changes in quality can have serious consequences. It is also important for the support of habitat and for maintaining the quality of baseflow to rivers. The chemical composition of groundwater is a measure of its suitability as a source of water for human and animal consumption, irrigation, and for industrial and other purposes. It also influences ecosystem health and function, so that it is important to detect change and early warnings of change both in natural systems and resulting from pollution.

Human Influence: Changes in natural baseline conditions may occur over the timescales of interest, and may be measured at an individual borehole or spring. Superimposed on these, however, are the greater impacts of human activities.

Practices in parks may influence groundwater quality. Approximately one mile south of the Canyonlands Visitor Center (Needles District) is an abandoned landfill that operated from 1966 to 1987. Hazardous substances including paint thinners, pesticides, human wastes, and oils were disposed at this landfill during operation. The soils consist of alluvial and eolian deposits (loose sandy material) of high permeability 10 to 20 feet deep; thus the potential for groundwater contamination exists in the area. The closest domestic well is 3,000 feet north of the landfill.

Groundwater chemistry in the unsaturated zone

Brief Description: Water moves downwards through porous soils and sediments and, under favorable conditions, may preserve a record of weathering processes, climatic variations (in the Cl or isotopic signature), or human activities such as agriculture (NO_3) and acidification (H^+). This indicator may be considered as the output from the soil zone and may reflect the properties or change in properties of soils. Rates of downward movement are typically 0.1 to 1.0 m/yr, and a record of individual events (resolution 1-20+ years) may be preserved over a scale of decades or centuries [see groundwater quality; soil quality]. In contrast, records collected over periods of years are needed to establish trends from the monitoring of rivers and streams or groundwater discharge [see groundwater quality; surface water quality]. The unsaturated zone is also an important buffering zone for attenuation of acidity, metal content, and some other harmful substances.

Significance: Changes in recharge rates have a direct relationship to water resource availability. The unsaturated zone may store and transmit pollutants, the release of which may have a sudden adverse impact on groundwater quality.

Human Influence: Depending on land use, the unsaturated zone beneath a site may record the effects of human activities such as agriculture and industrial activity, or regional problems such as acidic deposition.

Groundwater level

Brief Description: Groundwater is replenished from precipitation and from surface water, but the rate of abstraction (withdrawal by humans) may exceed the rate of natural recharge, leading to reduction of the resource. Some aquifers, especially in arid and semi-arid regions, contain paleowaters (fossil groundwater) stored from earlier periods of wetter climate; the reduction of these reserves is comparable to "mining." In alluvial plains, reduction in streamflow reduces the rate of natural recharge to aquifers. Measurement on a regular basis of water levels in wells and boreholes or of spring discharge provides the simplest indicator of changes in groundwater resources. However, springs may be perennial, intermittent, or periodic, and their discharge may depend on changes in climate, tides, and local underground conditions such as changes in rock stresses.

Significance: The availability of clean water is of fundamental importance to the sustainability of life. It is essential to know how long the resource will last and to determine the present recharge: groundwater mining is a terminal condition.

Human Influence: There are natural changes in groundwater levels because of climate change (drought, pluvial episodes), but the main changes are due to human abstraction. In many places artificial recharge of aquifers is accomplished deliberately by pumping or as an indirect result of irrigation.

The majority of available fresh water in Cape Cod National Seashore is groundwater. On the lower Cape, all groundwater has local precipitation as its source. The groundwater resource directly supports most of the lower Cape's surface water—ponds, streams, and fresh water wetlands. The human populations of the lower Cape are also entirely dependent on the groundwater for private and municipal water supply.

There are three primary groundwater withdrawal concerns facing Cape Cod National Seashore as development continues and the demand for new private and public water wells increases. First, excessive groundwater withdrawals can lower the local water table, potentially depleting pond, wetland, and vernal pool water levels. Second, large-scale, sustained pumping can decrease aquifer discharge, impacting streams and estuaries. Finally, under extreme cases, the groundwater volume may be depleted to a point where salt water intrudes and contaminates the fresh groundwater.

Karst activity

Brief Description: Karst is a type of landscape found on carbonate rocks (limestone, dolomite, marble) or evaporites (gypsum, anhydrite, rock salt) and is typified by a wide range of closed surface depressions, well-developed underground drainage system, and a paucity of surface streams. The highly varied interactions among chemical, physical, and biological processes have a broad range of geological effects including dissolution, precipitation, sedimentation, and ground subsidence. Diagnostic features such as sinkholes (dolines), sinking streams, caves, and large springs are the result of the solutional action of circulating groundwater, which may exit to entrenched effluent streams. Most of this underground water moves by laminar flow within narrow fissures, which may become enlarged above, at, or below the water table to form subsurface caves, in which the flow may become turbulent. Caves contain a variety of dissolution features, sediments, and speleothems (deposits with various forms and mineralogy, chiefly calcite), all of which may preserve a record of the geological and climatic history of the area. Karst deposits and landforms may persist for extraordinarily long times in relict caves and paleokarst. Karst can be either a sink or a source of CO_2, for the karst process is part of the global carbon cycle in which carbon is exchanged between the atmosphere, surface and underground water and carbonate minerals. Dissolution of carbonates, which is enhanced by the presence of acids in water, ties up carbon derived from the rock and from dissolved CO_2 as aqueous HCO_3-. Deposition of dissolved carbonate minerals is accompanied—and usually triggered—by release of some of the carbon as CO_2. In many karst locations, CO_2 emission is associated with the deposition of calcareous sinter (tufa, travertine) at the outlet of cold or warm springs.

Though most abundant in humid regions, karst can also be found in arid terrains where H_2S in groundwater, rising from reducing zones at depth, oxidizes to produce sulphuric acid, which can form large caves, such as the Carlsbad Caverns of New Mexico. Similar processes also operate in humid regions but tend to be masked by the CO_2 reaction. Sulphates and rock salt are rarely exposed in humid climates. They are susceptible to rapid dissolution during periodic rains where they are at the surface in drier terrains.

Significance: Karst systems are sensitive to many environmental factors. The presence and growth of caves may cause short-term problems, including bedrock collapse, disparities in well yields, poor groundwater quality because of lack of filtering action, instability of overlying soils, and difficulty in designing effective monitoring systems around waste facilities. Instability of karst surfaces causes damage to roads, buildings, and other structures. Radon levels in karst groundwater tend to be high in some regions, and underground solution conduits can distribute radon unevenly throughout a particular area.

Human Influence: Natural karst processes can be influenced by human activities such as land-use modification (e.g., deforestation), waste disposal, and opening or blocking of cave entrances, all of which can substantially affect sedimentation, speleothem deposition, and groundwater quality over the short term. Although most sinkhole collapse is triggered by high discharge of underground streams, lowering of water tables by overpumping in areas underlain by thick soils or weak rocks can induce ground failure and collapse into subsurface voids.

Lake levels and salinity

Brief Description: Lakes are dynamic systems that are sensitive to local climate and to land-use changes in the surrounding landscape [see shoreline position]. Some lakes receive their water mainly from precipitation, some are dominated by drainage runoff, and others are controlled by groundwater systems. On a time scale ranging from days to millennia, the areal extent and depth of water in lakes are indicators of changes in climatic parameters such as precipitation, radiation, temperature, and wind speed. Lake level fluctuations vary with the water balance of the lake and its catchment, and may, in certain cases, reflect changes in shallow groundwater resources.

Especially useful as climatic indicators are lakes without outlets (endorheic). In arid and semi-arid areas, the levels and areas of lakes with outflows are also highly sensitive to weather. Where not directly affected by human actions, lake level fluctuations are excellent indicators of drought conditions. Ephemerally- or seasonally-flooded lake basins (playas) are dynamic landforms, the physical character and chemical properties of which reflect local hydrologic changes, and which react sensitively to short-term climate changes (e.g., rate of evaporation). Fluctuations in lake water salinity also provide an indication of changes in conditions at the surface (climate, inflow/outflow relations) and in shallow groundwater [see sediment sequence and composition; surface water quality].

Significance: The history of fluctuations in lake levels provides a detailed record of climate changes on a scale of a decade to a million years. Lakes can also be valuable indicators of near-surface groundwater conditions.

Human Influences: Lake levels can be influenced by human-induced climate change, and by engineering works, such as dams and channels. Less drastic actions can also influence lake levels, for example, North Bar Lake in Sleeping Bear Dunes National Seashore, is an embayment lake that is being "loved to death." Historically, the lake was directly connected to Lake Michigan by an outlet channel. Heavy foot traffic has removed natural vegetation and destabilized the dunes near the lake. Increased sand transport from the dunes has filled in the outlet channel closing off the embayment lake, and, as a result, the embayment lake has lost its natural lake level fluctuation.

Relative sea level

Brief Description: The position and height of sea relative to the land (relative sea level - RSL) determines the location of the shoreline [see shoreline position]. Though global fluctuations in sea level may result from the growth and melting of continental glaciers, and large-scale changes in the configuration of continental margins and ocean floors, there are many regional processes that result in rise or fall of RSL that affect one coastline and not another. These include: thermal expansion of ocean waters, changes in meltwater load, crustal rebound from glaciation, uplift or subsidence in coastal areas related to various tectonic processes (e.g., seismic disturbance and volcanic action), fluid withdrawal, and sediment deposition and compaction. RSL variations may also result from geodetic changes such as fluctuations in the angular velocity of Earth or polar drift.

Significance: Changes in RSL may alter the position and morphology of coastlines, causing coastal flooding, waterlogging of soils, and a loss or gain of land. They may also create or destroy coastal wetlands and salt marshes, inundate coastal settlements, and induce salt-water intrusion into aquifers, leading to salinization of groundwater. Coastal ecosystems are bound to be affected, for example, by increased salt stress on plants. A changing RSL may also have profound effects on coastal structures and communities. Low-lying coastal and island states are particularly susceptible to sea-level rise.

Human Influences: Human actions including drainage of wetlands, withdrawal of groundwater (which eventually flows to the sea), and deforestation (which reduces terrestrial water storage capacity) may contribute to global rise in sea level. Human-induced climate change is also of obvious importance. Large engineering works, such as river channeling or dam construction, that influence sediment delivery and deposition in deltaic areas may cause local changes.

A big question in Cape Cod National Seashore is whether the marshes can keep up with sea-level rise. Cape Cod's fresh groundwater rests on seawater and necessarily rises along with sea level; therefore, the diked Pamet marsh, for example, continues to rise along with groundwater levels, but in a way that is very different from the way salt marshes normally grow. Salt marshes typically keep pace with sea-level-rise largely through the accumulation of inorganic sediment, i.e., sand, silt, and clay. The diked upper Pamet has been denied this sediment supply for over 100 years. In the meantime, any accretion has been through the production of organic matter.

Similarly, the engineering of the Mississippi River over the past 200 years has cut off sediment from nourishing and accreting the marshes at Jean Lafitte National Historical Park and Preserve (New Orleans, Louisiana), such that as the marshes subside, no new sediment is available to maintain marsh elevation.

Sediment sequence and composition

Brief Description: Lakes, wetlands, streams (and overbanks), estuaries, reservoirs, fjords, shallow coastal seas, and other bodies of marine or fresh water commonly accumulate deposits derived from bedrocks, soils, and organic remains within the drainage basin, though fine particles can also be blown in by winds from distant natural, urban, and industrial sources. These aquatic deposits may preserve a record of past or on-going environmental processes and components, both natural and human-induced, including soil erosion [see soil and sediment erosion; wetlands extent, structure, and hydrology], air-transported particulates [see dust storm magnitude, duration, and frequency], solute transport, and landsliding [see slope failure]. Some of these bodies of water are dynamic and sensitive systems whose sedimentary deposits preserve in their chemical, physical, and biological composition a chronologically ordered and resolvable record of physical and chemical changes through their mineralogy, structure, and geochemistry [see surface water quality]. Of particular value in determining long-term data on water chemistry are the remains of aquatic organisms, which can be correlated with various environmental parameters. In addition, fossil pollen, spores, and seeds reflect past terrestrial and aquatic vegetation. Sediment deposits can, thus, provide an indication of the degree and nature of impact of past events on the system, and a baseline for comparison with contemporary environmental change. Some lakes (and reservoirs) are open systems characterized by relatively stable shorelines and a limited residence time for solutes; others are closed (endorheic) and/or ephemeral (playas).

Significance: The chemical, physical, and biological character of aquatic sediments can provide a finely resolvable record of environmental change, in which natural events may be clearly distinguishable from human inputs.

Human Influence: Sediment deposition is a natural process that can be strongly influenced by human activities (e.g., land clearing, agriculture, deforestation, acidification, eutrophication, industrial pollution) within the drainage basin or sediment catchment.

George Washington Birthplace National Monument, specifically the Popes Creek watershed, serves as a reference system for environmental studies in the Chesapeake Bay region. Sediment sequences have recorded the history of farming and development beginning in colonial times. The farming activities and development in the Popes Creek watershed occurred at a much lower level than similar coastal plain watersheds in the area. The sediment sequence in Popes Creek watershed, which is geologically similar to other systems in the Chesapeake Bay region, has provided baseline information for the studies that examine the affects of human activities on natural processes.

Seismicity

Brief Description: Crustal movements along strike-slip, normal, and thrust faults cause shallow-focus earthquakes (those with sources within a few tens of kilometers of Earth's surface), though they can also be human-induced. They can result in marked temporary or permanent changes in the landscape, depending on the magnitude of the earthquake, the location of its epicenter, and local soil and rock conditions [see surface displacement]. Deep-focus earthquakes (below about 70 km), unless of the highest magnitude, are unlikely to have serious surface manifestations.

To avoid, reduce, or warn of environmental impacts, it is necessary to know the size, location, and frequency of seismic events. These parameters can identify active faults and the sense of motion along them. Also of great importance is the spatial pattern of seismicity, including the presence of seismic gaps, and the relationship to known faults and active volcanoes. At least three, and generally many more, monitoring sites are required to determine the necessary parameters.

Seismic observations constitute one of the oldest forms of systematic monitoring of earth processes. There are now in operation many national, regional, and international seismic networks, which provide information about the location, size, and motion of earthquakes anywhere in the world. However, shallow-focus tremors of lower magnitude, may not be detected by these means, and must be monitored more closely, on a local basis. Seismic hazard maps can be constructed to identify areas at varying risk from earthquake damage.

Significance: Earthquakes constitute one of the greatest natural hazards to human society. Surface effects include uplift or subsidence, surface faulting, landslides and debris flows, liquefaction, ground shaking, and tsunamis ("tidal" waves caused by undersea tremors). Damage to buildings, roads, sewers, gas and water lines, power and telephone systems, and other built structures commonly occur.

Human Influence: Earthquakes are predominantly natural events. However, shallow-focus seismic tremors can be induced by human actions that change near-surface rock stresses or fluid pressures. These actions include: extracting or injecting water, gas, petroleum, or waste fluids into the ground for storage or for secondary hydrocarbon recovery; mining or quarrying activities; and loading the surface with large water bodies (reservoirs). Underground explosions, particularly for nuclear testing, can also generate seismic events. Deep injection of water at the Potash Mine on the boundary of Canyonlands National Park is known to induce earthquakes.

Shoreline position

Brief Description: The position of the shoreline along ocean coasts and around inland waters (lakes) varies over a broad spectrum of time scales in response to shoreline erosion (retreat) or accretion (advance), changes in water level, and land uplift or subsidence [see relative sea level; surface displacement]. Long-term trends in shoreline position may be masked in the short term by variations over periods of days to years, related, for example, to individual storms, changes in storminess, and El Niño/Southern Oscillation effects. Shoreline position reflects the coastal sediment budget, and changes may indicate natural or human-induced effects alongshore or in nearby river catchments. The detailed shape and sedimentary character of a beach (e.g., beach slope, cusp dimensions, bar position and morphology, barrier crest and berm elevation, sediment size and shape) are highly sensitive to oceanographic forcing, including deep-water wave energy, nearshore wave transformation, wave setup, storm surge, tides, and nearshore circulation: morphodynamic adjustments and feedbacks are common. Qualitative assessments of shoreline morphology can be used as a proxy for shore-zone processes, partially substituting for more quantitative measures of shoreline change where these are not available.

Significance: Changes in the position of the shoreline affect transportation routes, coastal installations, communities, and ecosystems. The effects of shoreline erosion on coastal communities and structures can be drastic and costly. It is of paramount importance for coastal settlements to know if local shorelines are advancing, retreating, or stable.

Human Influence: Erosion and sediment accretion are on-going natural processes along all coasts. Human activities (e.g., dredging, beach mining, river modification, installation of protective structures such as breakwaters, removal of backshore vegetation, reclamation of nearshore areas) can profoundly alter shoreline processes, position, and morphology, in particular by affecting the sediment supply.

In Fire Island National Seashore, a groin was installed to protect a water tower at Ocean Beach from erosion by currents, tides, and waves. The effect of the groin was to cause accelerated erosion downshore. This retreat of shoreline continued to migrate downshore through the barrier island system at a rate of one kilometer per year, holding the shape of an eight-foot scarp in the sand. Rough calculations estimate human-induced changes to the shoreline position amount to approximately two meters of beach recession in the last 45-50 years.

Slope failure

Brief Description: There are many ways in which slopes may fail, depending on the angle of slope, the water content, the type of earth material involved, and local environmental factors such as ground temperature. Slope failure may take place suddenly and catastrophically or may be more gradual. Slope failure results in landslides, debris and snow avalanches, lahars, rock falls, flows (debris, quick clay, loess, and dry or wet sand and silt), slides (debris, rock), topples, slumps (rock, earth), and creep.

Special conditions and processes exist in permafrost terrains. Landslides and mudflows of permafrost regions are mobilized and shaped by the freezing and thawing of pore water in the active layer, the base of which acts as a shear discontinuity. Failure here can occur on slopes as low as 1º. Gelifluction (a form of solifluction, the slow downslope movement of waterlogged soil and surficial debris) is the regular downslope flow or creep of seasonally frozen and thawed soils. Gentle to medium slopes with blankets of loose rock fragments overlying frozen ground may be subject to mass movements such as rock glaciers and rock streams or kurums [see frozen ground activity]. Catastrophic slope failure here can expose new frozen ground, setting off renewed mass wasting.

Three parameters are particularly important for monitoring all kinds of mass movements:
1. **Ground cracks** are the surface manifestation of a variety of mass movements. In plan, they are commonly concentric or parallel, and have widths of a few centimeters and lengths of several meters, which distinguishes them from the much shorter desiccation cracks [see

desert surface crusts and fissures]. The formation of cracks and any increase in their rate of widening is a common measure of impending slope failure.

2. The appearance of and increases in **ground subsidence or upheaval** is also a good measure of impending failure.
3. The **area of slope failure** is a measure of the extent of landsliding in any region. Changes over time may both reflect significant environmental stresses (e.g., deforestation, weather extremes) and provide important clues about landscape and ecosystem degradation.

Climate change may accelerate or slow the natural rate of slope failure, through changes in precipitation or in the vegetation cover that binds loose slope materials. Wildfires can also promote mass movements by destroying tree cover. However, it is difficult to generalize where information is lacking on the present distribution and significance of landslides because many parameters, in addition to climate change, contribute to slope stability.

Significance: Slope failure causes death and property damage. Damage to ecosystems has not generally been documented, but landslides may destroy habitats, for example by blocking streams and denuding slopes.

Human Influence: Slope failure is a natural process that may be induced, accelerated, or retarded by human actions. Human influences include:

1. **Removal of lateral support** through human actions such as cutting slopes for roads and other structures, quarrying, removal of retaining walls, and lowering of reservoirs.
2. **Adding weight** to slopes by human actions such as landfills, stockpiles of ore or rock, waste piles, construction of heavy building and other structures, fill, and retaining walls.
3. **Vibrations** from explosions, machinery, road and air traffic.
4. **Decrease of underlying support** through mining.
5. **Lubricating slope materials** with water leaking from pipelines, sewers, canals, and reservoirs.

The Grand Ditch in Rocky Mountain National Park is a 16.2-mile aqueduct that diverts water from the West Slope streams to farms, ranches, towns, and cities on the eastern plains. Completed in 1936, it is one of the earliest transmountain diversions in Colorado. The Grand Ditch, which is cut into the mid- to upper slopes of the Never Summer Mountains, causes landslides in the upper Colorado River from undercutting the hillslope. Landslide material deposited in the Grand Ditch is side cast by bulldozers downslope when the ditch is cleaned annually.

<u>Soil and sediment erosion</u>

Brief Description: Erosion—the detachment of particles of soil and surficial sediments and rocks—occurs by hydrological (fluvial) processes of sheet erosion, rilling and gully erosion, and through mass wasting and the action of wind [see sediment geochemistry and stratigraphy; stream sediment storage and load; wind erosion]. Erosion, both fluvial and eolian (wind), is generally greatest in arid and semi-arid regions, where soil is poorly developed and vegetation provides relatively little protection. Where land use causes soil disturbance, erosion may increase greatly above natural rates. In uplands, the rate of soil and sediment erosion approaches that of denudation (the lowering of Earth's surface by erosional processes). In many areas, however, the storage of eroded sediment on hillslopes of lower inclination, in bottomlands, and in lakes and reservoirs, leads to rates of stream sediment transport much lower than the rate of denudation.

When runoff occurs, less water enters the ground, thus reducing plant productivity. Soil erosion also reduces the levels of the basic plant nutrients needed for growth, and decreases the diversity and abundance of soil organisms. Stream sediment degrades water supplies for municipal and industrial use, and provides an important transporting medium for a wide range of chemical pollutants that are readily sorbed on sediment surfaces. Increased turbidity of coastal waters due to sediment load may adversely affect organisms such as benthic algae, corals, and fish.

Significance: Soil erosion is an important social and economic problem and an essential factor in assessing ecosystem health and function. Estimates of erosion are essential to issues of land and water management, including sediment transport and storage in lowlands, reservoirs, estuaries, and irrigation and hydropower systems.

Human Influences: Erosion is a fundamental and complex natural process that is strongly modified (generally increased) by human activities such as land clearance, agriculture (ploughing, irrigation, grazing), forestry, construction, surface mining, and urbanization. Humans induce both water and wind erosion, which may result in chemical and physical deterioration of soil [see soil quality].

Within Sleeping Bear Dunes National Seashore, there are 11 major gravel and sand extraction pits or topsoil mining sites. The largest site is a 65-acre topsoil-mining site (STAN site); another site covers 40 acres on Scenic Drive.

Soil quality

Brief Description: Soils vary greatly in time and space. Over time-scales relevant to geoindicators, they have both stable characteristics (e.g., mineralogical composition and relative proportions of sand, silt, and clay) and those that respond rapidly to changing environmental conditions (e.g., ground freezing). The latter characteristics include soil moisture and soil microbiota (e.g., nematodes, microbes), which are essential to fluxes of plant nutrients and greenhouse gases. The soils of boreal regions are estimated to hold the equivalent of some 60% of the current atmospheric carbon: long-term warming is expected to increase decomposition and drying, thus potentially releasing huge volumes of methane and CO_2.

Most soils resist short-term climate change, but some may undergo irreversible change such as lateritic hardening and densification, podsolization, or large-scale erosion. Soil properties and climatic variables such as mean annual rainfall and temperature can be related by mathematical functions known as climofunctions.

Chemical degradation takes place because of depletion of soluble elements through rainwater leaching, overcropping and overgrazing, or because of the accumulation of salts precipitated from rising groundwater or irrigation schemes. It may also be caused by sewage containing toxic metals, precipitation of acidic and other airborne contaminants, as well as by persistent use of fertilizers and pesticides. A widespread problem is the retention in the soil organic matter and clay minerals of potentially toxic metals and radionuclides (e.g., Cu, Hg, Pb, Zn, ^{226}Ra, ^{238}U). These and other chemical components may be catastrophically released as what are commonly referred to as “chemical time bombs” where the pH of the soil is decreased by acidification or where other environmental disturbances (e.g., erosion, drought, land use change) intervene. Soils also act as a primary barrier against the migration of organic contaminants into groundwater. Key indicators are pH, organic matter content, sodium absorption ratio, cation exchange capacity, and cation saturation.

Physical degradation results from land clearing, and erosion and compaction by machinery. Soil structure may be altered so that infiltration capacity and porosity are decreased, and bulk density and resistance to root penetration are increased. Such soils have impeded drainage and are quickly saturated: the resultant runoff can cause accelerated erosion and transport of pollutants such as pesticides [see soil and sediment erosion]. The key soil indicators are texture (especially clay content), bulk density, aggregate stability and size distribution, and water-holding capacity.

Significance: As one of Earth’s most vital ecosystems, soil is essential for the continued existence of life on the planet. As sources, stores, and transformers of plant nutrients, soils have a major influence on terrestrial ecosystems. Soils continuously recycle plant and animal remains, and they are major support systems for human life, determining the agricultural production capacity of the land. Soils buffer and filter pollutants; they store moisture and nutrients; and they are important sources and sinks for CO_2, methane, and nitrous oxides. Soils are a key system for the hydrological cycle [see groundwater chemistry in the unsaturated zone]. Soils also provide an archive of past climatic conditions and human influences.

Human Influences: Soils may be degraded or enhanced by both natural processes and human activities. Human activities influence soil properties by causing increases in bulk density from agricultural tillage and road operations and in acidification from inorganic fertilizers and acid rain. Soil degradation is one of the largest threats to environmental sustainability.

Streamflow

Brief Description: Streamflow varies with the volume of water, precipitation, surface temperature, and other climatic factors. For most streams (rivers), the highest water discharge is found close to the sea, but in arid regions discharge decreases naturally downstream. Land use in drainage basins also strongly affects streamflow. Major streamflow regimes include glacial, nival, dry tropical, monsoon, equatorial, and desert. Reversals in streamflow, in conjunction with indirect methods of paleoflood studies and paleohydrology, yield long-term indicators of changes in discharge that are valuable for responses to flooding, estimating long-term trends in water and sediment discharges, and for distinguishing possible long-term climate change.

Significance: Streamflow directly reflects climatic variation. Stream systems play a key role in the regulation and maintenance of biodiversity. Changes in streams and streamflow are indicators of changes in basin dynamics and land use.

Human Influences: Natural variations in streamflow predominate, but they can be strongly modified by human actions, such as dams and reservoirs, irrigation, and diversion for use outside the watershed.

Only two perennial streams, Leach and Little Cottonwood Creeks, are present in Craters of the Moon National Monument. These streams drain the Pioneer Mountains in the north end of the park. Diversion of streamflow in Little Cottonwood Creek began in the 1930s for park operations. Water demand was low until the late 1950s when the visitor center complex was built. It is estimated that peak consumption occurred in the late 1960s when over 50% of the streamflow was diverted out of the channel. At present (2000) this use has decreased to approximately 30% due to the reduction in the area of irrigated lawns.

Stream channel morphology

Brief Description: Alluvial streams (rivers) are dynamic landforms subject to rapid change in channel shape and flow pattern. Water and sediment discharges determine the dimensions of a stream channel (width, depth, and meander wavelength and gradient). Dimensionless characteristics of stream channels and types of pattern (braided, meandering, straight) and sinuosity are significantly affected by changes in flow rate and sediment discharge, and by the type of sediment load in terms of the ratio of suspended to bed load [see stream sediment storage and load]. Dramatic changes in stream bank erosion within a short time period indicate changes in sediment discharge.

Significance: Channel dimensions reflect magnitude of water and sediment discharges. In the absence of hydrologic and streamflow records, an understanding of stream morphology can help delineate environmental changes of many kinds. Changes in stream pattern, which can be very rapid in arid and semi-arid areas, place significant limits on land use, such as on islands in braided streams and meander plains, or along banks undergoing erosion.

Human Influences: Significant changes in stream dimensions, discharge, and pattern may reflect human influences such as water diversion and increased sediment loads resulting from land clearance, farming, or forest harvesting. Such variations are also responsive to climatic fluctuations and tectonics.

Only two perennial streams, Leach and Little Cottonwood Creeks, are present in Craters of the Moon National Monument. There is evidence that the lower portion of Little Cottonwood Creek was historically diverted out of its natural channel. The creek makes a 90º bend, and a line of dead cottonwood trees and a ground depression indicate where the channel used to be. The channel morphology of Leach Creek has also been altered. There are old impoundments or control structures in the upper portion of the creek. A dry channel in the lower portion indicates that the creek was historically diverted out of its natural channel. Both creeks continue to be diverted out of their original channels (2000).

Stream sediment storage and load

Brief Description: The load (discharge, tonnes/year) or yield (tonnes/km^2/year) of sediment (in suspension and as bed load of sand and gravel) through stream (river) channels reflects upland erosion within the drainage basin and change in storage of sediment in alluvial bottomlands [see soil and sediment erosion]. In turn, climate, vegetation, soil and rock type, relief and slope, and human activities such as timber harvesting, agriculture, and urbanization influence stream sediment storage and load. Much of the sediment eroded from upland areas is deposited (stored) on lower hillslopes, in bottomlands, and in lakes and reservoirs. Flash floods in ephemeral desert streams may transport very large sediment loads, accounting for unforeseen sedimentation problems in dryland stream reservoirs.

Significance: Sediment load determines channel shape and pattern [see stream channel morphology]. Changes in sediment yield reflect changes in basin conditions, including climate, soils, erosion rates, vegetation, topography, and land use. Fluctuations in sediment discharge affect a great many terrestrial and coastal processes, including ecosystem responses, because nutrients are transported together with the sediment load. For example, to reproduce effectively, salmon and trout need gravel stream beds for spawning and egg survival; silt and clay deposits formed by flooding or excessive erosion can destroy these spawning beds. Stream deposits also represent huge potential sinks for, and sources of, contaminants.

Human Influences: Stream sediment storage and load is influenced strongly by human actions, such as in the construction of dams and levees, forest harvesting, and farming in drainage basins.

Subsurface temperature regime

Brief Description: Temperatures in boreholes a few hundred meters deep can be an important source of information on recent climatic changes because the normal upward heat flow from Earth's crust and interior is perturbed by the downward propagation of heat from the surface. As temperature fluctuations are transmitted downward, they become progressively smaller, with shorter-period variations attenuating more rapidly than longer ones. Although seasonal oscillations may be undetectable below about 15 m, century-long temperature records may be observed to depths of 150 m or so. Bedrocks thus selectively retain the long-term trends required for reconstructing climate change.

The surface temperature is strongly affected by local factors such as thickness and duration of snow cover, type of vegetation, properties of organic soil layers, depth to the water table, and topography. It influences, in turn, a wide range of ground and surface processes, particularly in the near-surface portions of permafrost [see frozen ground activity]. Below the active layer, where ground temperature fluctuates seasonally as thawing and freezing take place, long-term temperature variations may be recorded. Here, repeated measurements of soil temperature at fixed locations can reveal both the long-term dynamics of seasonally frozen ground and long-term climatic fluctuations, though the conversion of ground temperature to climate history is a complex matter.

Significance: The thermal regime of soils and bedrocks exercises an important control on the soil ecosystem, on near-surface chemical reactions (e.g., involving groundwater), and on the ability of these materials to sequester or release greenhouse gases. It may affect the type, productivity, and decay of plants; the availability and retention of water; the rate of nutrient cycling; and the activities of soil microfauna. It is also of major importance as an archive of climate change, indicating changes in surface temperature over periods of up to 2-3 centuries, for example in regions without a record of past surface temperatures. In permafrost, the ground temperature controls the mechanical properties of the soils, especially during the freeze-thaw transition in the active layer.

Human Influence: The subsurface temperature regime reflects both the natural geothermal flux from Earth's interior and the surface temperature. The latter can be modified by human actions, such as land clearing, wetland destruction, agriculture, deforestation, flooding of land for reservoirs, or development of large settlements that give rise to a "heat island" effect.

Surface displacement

Brief Description: Earth's surface is subject to small but significant displacements (uplift, subsidence, lateral movement, rotation, distortion, dilation) that affect elevation and horizontal position. These movements result from active tectonic processes, collapse into underground cavities, or the compaction of surficial materials. Sudden movements may be caused by faulting associated with earthquakes [see seismicity], and from the collapse of rock or sediment into natural holes in soluble rocks (e.g., salt, gypsum, limestone) [see karst activity], or into cavities produced by mining of near-surface rocks (especially coal) and solution-mining of salt. Slower local subsidence may also be induced by: fluid withdrawal (gas, oil, groundwater, geothermal fluids); densification or loss of mass in peat being developed for agriculture; drainage of surface waters from wetlands, which can cause oxidation, erosion, and compaction of unconsolidated soils and sediments [see wetlands extent, structure, and hydrology]; and filtration of surface water through porous sediments such as loess. On a much larger scale, the land surface elevation responds slowly to plate movements, compaction of sedimentary basins, and glacial rebound.

Fissures and faults can develop suddenly during earthquakes and as a result of volcanic processes and landsliding, or more slowly as a result of differential compaction during subsidence. In arid and semi-arid terrains, fissures up to several kilometers long and a few centimeters wide may be rapidly eroded by surface run-off to gullies.

Significance: Most surface displacements have but minor effects on landscapes and ecosystems. However, there are exceptions, such as where drainage channels are suddenly displaced by faults, or where seismically-induced uplift raises intertidal ecosystems above sea-level. Moreover, extraction of fluids beneath urban areas can induce land subsidence and cause flooding, especially of coastal communities near sea-level. Subsidence damages buildings, foundations, and other built structures.

Human Influence: Surface displacements are natural phenomena associated with plate movements, glacial rebound, and faulting, but human activities such as extraction of groundwater, oil, and gas can also induce surface subsidence.

In Cape Cod National Seashore, surface displacement is linked to other geoindicators: relative sea level and wetlands. Ditching and diking of formerly tidal wetlands have caused significant subsidence within the Seashore. The subsidence is significant not with respect to aerial extent, but to the sensitivity of habitats affected and the challenge subsidence poses to restoration efforts.

Surface water quality

Brief Description: The quality of surface water in rivers and streams, lakes, ponds, and wetlands is determined by interactions with soil, transported solids (organics, sediments), rocks, groundwater, and the atmosphere. It may also be significantly affected by agricultural, industrial, mineral and energy extraction, urbanization, and other human actions, as well as by atmospheric inputs. The bulk of the solutes in surface waters, however, are derived from soils and groundwater baseflow where the influence of water-rock interactions is important [see groundwater quality; karst activity; soil and sediment erosion; soil quality; streamflow; wetlands extent, structure, and hydrology].

Significance: Clean water is essential for the survival of all forms of life. Most is used for irrigation, with lesser amounts for municipal, industrial, and recreational purposes; only 6% of all water is used for domestic consumption. Pathogens such as bacteria, viruses, and parasites are among the world's most dangerous environmental pollutants and cause water-borne diseases. Water quality data are essential for the implementation of responsible water quality regulations, for characterizing and remediating contamination, and for the protection of the health of humans and other organisms.

Human Influence: The water quality of a lake, reservoir, or river can vary in space and time according to natural morphological, hydrological, chemical, biological, and sedimentological processes (e.g., changes of erosion rates). Pollution of natural bodies of surface water is widespread because of human activities, such as disposal of sewage and industrial wastes, land clearance, deforestation, use of pesticides, mining, and hydroelectric developments.

Trespass cattle at springs in Arches National Park raise a concern regarding maintenance of good water quality. Impacts include trampled soil and vegetation, increased sedimentation, and elevated levels of fecal contamination.

Herbicides to decrease the number of tamarisk stands may cause water quality problems associated with streams and springs in Arches National Park, Canyonlands National Park, and Natural Bridges National Monument.

Volcanic unrest

Brief Description: Eruptions are almost always preceded and accompanied by volcanic unrest, indicated by variations in the geophysical and geochemical state of the volcanic system. Such geoindicators commonly include changes in seismicity, ground deformation, nature and emission rate of volcanic gases, fumarole and/or ground temperature, and gravity and magnetic fields. Volcanic unrest can also be expressed by changes in temperature, composition, and level of crater lakes, and by anomalous melting or volume changes of glaciers and snow fields on volcanoes. When combined with geological mapping and dating studies to reconstruct comprehensive eruptive histories of high-risk volcanoes, these geoindicators can help to reduce eruption-related hazards to life and property. However, not all volcanic unrest culminates in eruptions; in many cases the unrest results in a failed eruption in which the rising magma does not breach the surface and erupt.

Significance: Natural hazards associated with eruptions pose a significant threat to human and animal populations. Before 1900, two indirect hazards—volcanogenic tsunamis and post-eruption disease and starvation—accounted for most of the eruption-associated human fatalities. In the 20th century, however, direct hazards related to explosive eruptions (e.g., pyroclastic flows and surges, debris flows, mudflows) were the most deadly hazards.

Human Influence: None. Volcanism is a natural process that has operated since the formation of Earth. Although a few attempts have been made to divert lava flows, humans have had no influence whatsoever on the underlying causes of volcanism.

Wetlands extent, structure, and hydrology

Brief Description: Wetlands are complex and sensitive ecosystems, characterized by a water table at or near the land surface for some part of the year, by soil conditions that differ from adjacent uplands, and by vegetation adapted to wet conditions. Wetlands are usually classified on the basis of their morphology and vegetation and, to a lesser extent, their hydrology. Though definitions vary, the following types are widely recognized: coastal salt and freshwater marshes; swamps (mangrove, shrub, and wooded); wet grasslands, meadows, and prairies; and peatlands (landforms in which organic sediments have accumulated to depths in excess of 30-50 cm), including mires, moors, muskeg, bogs, and fens.

The areal extent, distribution, and surface and internal structures of a wetland can be altered by many processes, such as organic and inorganic sediment deposition and erosion, paludification (lateral spread), terrestrialization (colonization of open water by wetland plant communities), and changing hydrology. In the case of coastal wetlands, saltwater intrusion and changes in sea level can also be important [see relative sea level; shoreline position].

Hydrological relationships play a key role in wetland ecosystem processes, and in determining structure and growth. Different wetlands have a characteristic hydroperiod, or seasonal pattern of water levels, that defines the rise and fall of surface and subsurface water. An important geoindicator is the water budget of a wetland, which links inputs from groundwater, runoff, precipitation, and physical forces (wind, tides) with outputs from drainage, recharge, evaporation, and transpiration. Annual or seasonal changes in the range of water levels affect visible surface biota, decay processes, accumulation rates, and gas emissions. Such changes can occur in response to a range of external factors, such as fluctuations in water source (river diversions, groundwater pumping), climate, or land use (forest clearing). Waters flowing out of wetlands are chemically distinct from inflow waters, because a range of physical and chemical reactions take place as water passes through organic materials, such as peat, causing some elements (e.g., heavy metals) to be sequestered and others (e.g., DOC, humic acids) to be mobilized. A baseline of wetland conditions may be established through a paleoecological study to investigate whether a present-day wetland is stable or actively evolving, and if so in what direction and at what rate.

Significance: Wetlands are areas of high biological productivity and diversity. They provide important sites for wildlife habitat and human recreation. Wetlands mediate large- and small-scale environmental processes by altering downstream catchments. The dissolved carbon burden of wetlands may affect downstream waters, for example by acid drainage. Wetlands can affect local hydrology by acting as a filter, sequestering and storing heavy metals and other pollutants, such as Hg, and serving as flood buffers and, in coastal zones, as storm defenses and erosion controls.

Wetlands can act as carbon sinks, storing organic carbon in waterlogged sediments. Even slowly growing peatlands may sequester carbon at between 0.5 and 0.7 tonnes/ha/yr. Wetlands can also be a carbon source, when it is released via degassing during decay processes, or after drainage and cutting, as a result of oxidation or burning.

Human Influence: Wetlands develop naturally in response to morphological and hydrological features of the landscape. Their evolution can be affected by external factors such as climate change, landscape processes (e.g., coastal erosion), or human activity (draining, channeling of local rivers, water abstraction and impoundment, forest clearance). Wetlands can be lost to drainage for agriculture or settlement or to harvesting for commercial purposes.

Diking and drainage in the late 19th century and freshwater impoundment in the mid-20th century have interrupted the evolution of salt marshes in the upper Pamet River in Cape Cod National Seashore. These hydrologic alterations have caused vegetation to shift from salt-tolerant grasses to salt-intolerant herbs, trees, and shrubs and have caused the wetland surface to subside well below the elevation of modern, undiked marshes.

<u>Wind erosion</u>

Brief Description: The action of wind on exposed sediments and friable rock formations causes erosion (abrasion) and entrainment of sediment and soil particles [see dust storm magnitude, duration, and frequency]. Eolian action also forms and shapes sand dunes, yardangs (streamlined bedrock hills), and other landforms. Subsurface deposits and roots are commonly exposed by wind erosion. Wind can also reduce vegetation cover in wadis and depressions, scattering the remains of vegetation in interfluves. Stone pavements may result from the deflation (removal) of fine material from the surface leaving a residue of coarse particles. Blowouts (erosional troughs and depressions) in coastal dune complexes [see dune formation and reactivation] are important indicators of changes in wind erosion. The potential for deflation is generally increased by shoreline erosion or washovers, vegetation die-back (due to soil nutrient deficiency or to animal activity), and human actions such as recreation and construction.

Significance: Changes in wind-shaped surface morphology and vegetation cover that accompany desertification, drought, and aridification are important gauges of environmental change in arid lands. Wind erosion also affects large areas of croplands in arid and semi-arid regions, removing topsoil, seeds, and nutrients.

Human Influence: Eolian erosion is a natural phenomenon, but the surfaces it acts upon may be made vulnerable by human actions, especially those, such as cultivation and over-grazing, that result in the reduction of vegetative cover.

Currently in Cape Cod National Seashore, human actions [e.g., use of ORVs (off-road vehicles) and the proliferation of social trails] influence wind erosion. Degraded areas are limited, but it is of high management significance because of the impacts on popular areas, such as Herring Cove. Aerial photographs revealed a “spider web” of social trails in this area.

Appendix B: Human Influences

The term "human influences" is the central theme for the second part of GPRA goal Ib4. The term has purposefully been selected in order to explore the full breath of human activities, both inside national parks and external to the park boundaries. Adjacent land use, consumptive activities, administrative practices, and visitor use can all influence earth surface processes. An effective way to illustrate human influences on earth surface processes is to go through some examples. This is not a comprehensive treatment, and these examples do <u>not</u> occur in all parks. These examples are provided to raise awareness, stimulate the reader's thinking, and perhaps cause the reader to contemplate additional cases from his or her own experience.

Land Use

- Agriculture – Intense use can cause loss of soil, erosion, and dust storms. Use of pesticides can affect both surface water and groundwater quality.
- Grazing – Overgrazing can cause loss of vegetation, invasion of exotic species, soil erosion, and nutrient loss.
- Forestry – Intense logging or clear cutting creates conditions for increased erosion; eroded and transported sediment can cause increased sediment loading in streams, which could affect fluvial habitat.
- Water impoundment – This has the potential to affect one segment of a stream or river or an entire watershed. Controlled volume of flow does not duplicate natural events, such as floods and drought. It can affect the sediment load, change the stream morphology, and alter the habitat that is dependent on a fluvial system.
- Urbanization – This can cause a host of impacts, but a few stand outs are: change in drainage patterns because of impervious surfaces (streets, parking lots, pavement, buildings), increased erosion, affects on surface and groundwater quality and quantity, release of toxins into the air, increased humidity in arid regions.
- Alterations to shorelines – Dredging, beach mining, river modification, installation of protective structures, and removal of back-shore vegetation can potentially alter shoreline processes, position, and morphology by changing the sediment supply, transport, and erosion.

Consumptive Use

- Groundwater withdrawal –This sustainable, renewable resource can become a non-renewable, mined one, if groundwater withdrawal exceeds recharge. Mining groundwater is terminal and affects and entire ecosystem (both living and non-living components). Where withdrawal has been intense for decades, the surface has been known to collapse (subside) over many acres to depths of over ten feet.
- Oil and gas production – This can cause surface subsidence and cause contamination of water aquifers and cave & karst systems. Oil and gas operations can leave a considerable "footprint" on the land, such as roads (created during seismic tests and well operation), pipelines, facilities, storage tanks, and well pads.
- Mining (open pit and underground) – It can reconfigure the landscape over large areas bringing significant and permanent change to the landscape. It can affect groundwater by releasing heavy metals or other chemicals into the system.
- Mineral Materials Mining – If performed in sensitive ecosystems or with respect to volume of material removed, the quarrying of stone, mining of gravel, and borrowing of soil can impact geologic process.

- Extirpation of species – This can affect both the living and non-living components of an ecosystem. Take the elimination of beaver from an ecosystem, for example. This can alter water impoundment, sediment load, timing of sediment release, and stream channel morphology.

Administrative Use

- Roads & bridges – Often these have been constructed with little or no consideration for natural processes. Roads can disrupt drainage, cause erosion, and create hillslope instability. The abutments for bridges can change the flow and morphology of streams and rivers.
- Parking lots – Construction, location, and drainage off parking lots can cause harm. Large paved areas (acres) deprive the surface of an opportunity to absorb precipitation. Water flowing from the parking lots can cause erosion and gullying if not properly directed. Runoff pollution affects surface water and groundwater.
- Facilities placed over karst and caves – Contaminants and runoff from restrooms and other water usage can reach cave and karst systems below Earth's surface and cause damage to the fragile subterranean ecosystem.
- Water consumption – Parks located in arid environments need special consideration for all aspects of water usage (restrooms, watering lawns, domestic use for staff, maintenance shops, etc.)
- Trails – If they are poorly located with respect to soil, rockwalls, wetlands, and sensitive vegetation, they have the potential to exacerbate erosion, rock falls, and slope instability. The placement of snowmobile trails can influence slope stability and cause avalanches.
- Armoring – Through engineering efforts, humans have attempted to impose stability on naturally dynamic and ever-changing environments along streams, rivers, coastlines, and shorelines. Structures interfere with the transport of sand and sediment and aggravate erosion over the long-term.
- Planting exotic species – Planting non-native species on sand dunes to hold them in place disrupts eolian processes that drive an ecosystem.
- Fire – Fires directly affect slope stability and can cause debris flows on steep slopes.

Visitor Use

- Compaction of soils – Over use by recreationists (hiking, horseback riding, mountain biking, OHV's) can compact soil, which diminishes its capability to function and maintain itself as a viable part of the ecosystem.
- Social trails – Depending on the fragile nature of the environment, wandering off-trail can seriously damage fragile resources (caves, wetlands, soil crusts, cinder cones, tundra, etc.)
- Touching fragile features – A number of geologic features have taken years to form through geologic processes, and although seemingly rock-hard, they may be fragile. Examples include stalactites and stalagmites in caves. Also included are erosional features, such as arches, bridges, hoodoos, and badlands. Crystals are another example. Visitors touching or climbing on all these features can cause irreparable damage.
- Power boating – Over a period of time, wakes from small and large boats alike can contribute to shoreline erosion. Fuel contamination can affect water quality.

Appendix C: Introducing Geoindicators

What are Geoindicators?

Geoindicators constitute an approach for identifying rapid changes in the natural environment. An international Working Group of the International Union of Geological Sciences (IUGS) developed geoindicators in order to access common geological processes occurring at or near Earth's surface that may undergo significant change in magnitude, frequency, trend, or rates, over periods of 100 years or less. Geoindicators measure both catastrophic events and those that are more gradual but evident within a human lifespan. Some geoindicators can provide a record of natural events through time.

The 27 geoindicators are:

1. Coral chemistry and growth patterns
2. Desert surface crusts and fissures
3. Dune formation and reactivation
4. Dust storm magnitude, duration, and frequency
5. Frozen ground activity
6. Glacier fluctuations
7. Groundwater quality
8. Groundwater chemistry in the unsaturated zone
9. Groundwater level
10. Karst activity
11. Lake levels and salinity
12. Relative sea level
13. Sediment sequence and composition
14. Seismicity
15. Shoreline position
16. Slope failure
17. Soil and sediment erosion
18. Soil quality
19. Streamflow
20. Stream channel morphology
21. Stream sediment storage and load
22. Subsurface temperature regime
23. Surface displacement
24. Surface water quality
25. Volcanic unrest
26. Wetlands extent, structure, hydrology
27. Wind erosion

Why are Geoindicators important?

Ecosystem management, reporting, and planning generally focus on biological issues such as biodiversity, threatened and endangered species, exotic species, and biological and chemical parameters relating to pollution (e.g., air and water quality). Much less attention is paid to the physical processes that shape the landscape—the natural, changing foundation on which humans and all other organisms live and function.

Geoindicators help answer NPS resource management questions about what is happening to the environment, why it is happening, and whether it is significant. They establish baseline conditions and trends, so that human-induced changes can be identified. Applying the geoindicators approach will provide science-based information to support resource management decisions and planning. Geoindicators help non-geoscientists focus on key geological issues, help parks anticipate what changes might occur in the future, and identify potential management concerns from a geological perspective.

Geology and geological processes are integral to park management and planning. For example, the underlying geology and soils influence natural vegetation patterns, and in turn exert a control on biological communities. Geological processes can affect park roads, infrastructure, and facilities. When measures of natural landscape change are omitted from monitoring and planning, the assumption that natural systems are stable, fixed, and in equilibrium is perpetuated. Natural systems are dynamic, and some may be chaotic; change is the rule, not the exception.

Monitoring the abiotic components of ecosystems using geoindicators will help to emphasize this point.

The geoindicators approach can be a useful reminder both of the prevalence of natural fluctuations and of the difficulty of separating them from human-induced environmental change. Using geoindicators shifts management actions from response (crisis mode) to long-range planning, so issues can be recognized before they become concerns. Geoindicators may also prove to be useful tools for enhancing interdisciplinary research and communication, a way to connect with others concerned with environmental issues and problems.

How do Geoindicators fit into the National Park Service's strategic plan?
In 1999, the NPS Geologic Resources Division (GRD) and the NPS Strategic Planning Office cooperated to develop a Servicewide geologic resource goal as part of the Government Performance and Results Act (GPRA). The NPS Goal Ib4 states, "Geological processes in 75 parks (36% of 270 natural resource parks) are inventoried and human influences that affect those processes are identified." This goal was designed to increase understanding of geological processes and their functions in ecosystems and to help park managers make more informed science-based management decisions.

This goal is intended to be the first step in a process that will lead to inventory, monitoring, and research, and ultimately focus on the mitigation or elimination of human activities that severely impact geological processes, harm geologic features, or cause critical imbalance in ecosystems.

What is the purpose of a Geoindicators scoping meeting?
The purpose of a scoping meeting is to identify significant geological processes in a park's ecosystem and determine if those processes are being affected by human activities. Pertinent human influences may include visitor impacts, park management practices and developments, land use adjacent to parks (e.g., pollutants, timber harvest), and global issues (e.g., industrial dust from China).

In addition, resource management issues related to geology and geological processes will be identified; and inventory, monitoring, and research studies that can provide scientific data to be used in making management decisions will be recommended.

How does the Geoindicators scoping process work?
The GRD coordinates efforts between park resource managers and geologists (from federal and state agencies and academia) through scoping meetings that are held in national parks. The scoping meetings are designed to use the participants' current expertise and institutional knowledge and build on the synergy of the participants through field observations, group discussion, and the exchange of ideas. For park staff, the scoping meetings foster a better understanding of the physical resources and geological processes in the park. For scientists, the scoping meetings foster an awareness of management issues and the decision-making and planning processes preformed by park staff.

The field trip portion of a scoping meeting highlights the park's setting and geology, as well as key resource management issues related to geological processes. During the discussion portion of a scoping meeting, selected geoindicators—specific to a park's setting—guide and focus the dialog.

The following questions are addressed during the group discussion of a scoping meeting. The answers are rated and prioritized.

- What are the significant geological processes in the park's ecosystems? Why are they significant?

- Which of these geological processes is being influenced by human activities both from inside and outside the park?

- How significant to park management are the identified geological processes and associated human influences?

- What sort of geological baseline data would benefit the park?

- What geoindicators should be monitored in the park? What protocols are recommended and who are the geoscientists to contact?

- Where are the information gaps? What studies or research are recommended?

- What information should be included in park planning documents?

What are the outcomes of a Geoindicators scoping meeting?
Scoping meetings provide an opportunity for park staff and geologists to connect and build relationships. This is significant because many park managers do not have easy access to geological expertise, and most do not have geologists on staff or in their regional offices.

Managers from participating parks will receive a summary report that highlights the recommendations identified during the scoping meeting. Recommendations include inventory and monitoring—which will provide information to use for park planning and decision-making—and research topics that will fill information gaps.

Where can I get more information?
- Web site about geologic resource monitoring in the U.S. National Parks: http://www2.nature.nps.gov/grd/geology/monitoring/index.htm.

- Detailed descriptions of the 27 geoindicators: http://www2.nature.nps.gov/grd/geology/monitoring/parameters.htm.

- Web site of the IUGS Geoindicators Initiative: http://www.lgt.lt:8080/geoin/welcome.

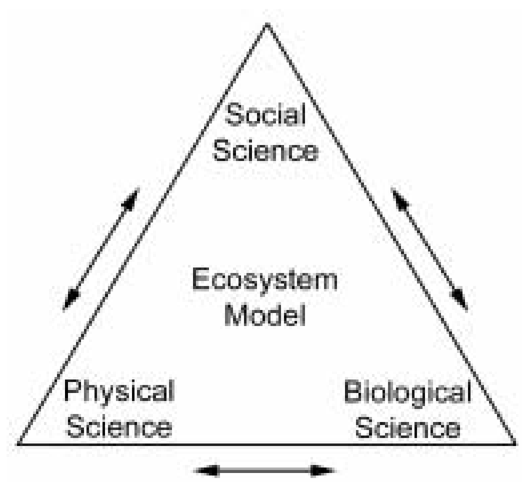
Appendix D: Species Don't Stand Alone—Geology's Role in Ecosystems

Ecology's fundamental insight for ecosystem management is that species do not stand alone. Organisms are dynamically and interactively enmeshed in the abiotic ecosystem matrix. Increasingly, ecologists and land-management agencies are recognizing that species—the living components of ecosystems—cannot be conserved without conserving the non-living components, which help shape ecosystem structure and function (Pickett et al., 1992; Christensen et al., 1996). As "matrix sciences," physical sciences such as geology, soil science, hydrology, and climatology play a fundamental role in conservation and ecosystem management.

The founder of modern ecosystem ecology was a soil scientist, Hans Jenny (Vitousek, 1994), and James Lovelock, a geophysicist, conceptualized Planet Earth as a functional ecosystem composed of functional subsystems (Rowe, 2001). Yet despite these historical connections between the sciences and the tremendous importance of the matrix sciences to ecosystem studies, most ecosystem mangers have not traditionally integrated the biological and physical sciences in resource managment. The problem may be that most ecosystem managers/ecologists have been educated in biology departments and trained to focus on species (Rowe, 2001). Thus, the abiotic components of an ecosystem often enter management discussions as an afterthought, of secondary importance and vaguely associated with the fuzzy term "habitat," if they enter the discussion at all.

Over the last two decades, however, the focus of land management has slowly been shifting to a truly integrated, ecosystem approach—one that recognizes that species do not stand alone—and incorporates biological, geological, and social components (Figure 1). This change is particularly important as resource managers strive to gain greater predictive and mechanistic understanding of ecosystem responses to human activities. This approach identifies a need to devote increased attention to the geosciences, and especially to the interactions between the geological and biological systems.

Figure 1. Relationship of component parts to an ecosystem.



Geological processes create topographic highs and lows; impact water and soil chemistries; influence the fertility of soils, the stability of hillsides, and the flow styles of surface water and groundwater (Swanson et al., 1988). These factors, in turn, determine where and when biological processes occur, such as the timing of species reproduction, the distribution of habitats, the productivity and type of vegetation, and the response of ecosystems to human impacts. Likewise, biological processes affect geological processes. Biological activity contributes to soil formation and soil fertility, controls hillside erosion, traps blowing sand to form dunes, stabilizes drainages, and attenuates floods.

The geological resources of a park—soils, caves, glaciers, streams, springs, volcanoes, etc.—provide the physical foundations required to sustain the biological system. Human influences on geological processes and alteration of geological features inevitably affect habitat conditions. For example, the channelization of the Virgin River in Zion National Park caused the channel to incise, lowering the groundwater table and reducing the habitat of floodplain obligate species (Smith, 1998; Steen, 1999). In Jean Lafitte National Historical Park and Preserve, externally triggered land subsidence is raising the water level in the park, thereby inundating the swamp forest and reducing habitat for forest-dependent species (Sauier, 1994). Alternatively, a manipulation of the biological system can trigger changes in the geological system that can re-affect the biological system. For example, when beaver are trapped to increase the density of hydrophobic shrub species, the river morphology and sediment transport capacity change, resulting in a redistribution of the types of fish species. Geological resources also influence the impacts of natural variation in factors such as climate or human activity. The availability of water, the stability of soil surfaces, and nutrient supply from weathering rocks are all examples of underlying physical controls on biological processes.

A challenge in appreciating the relevance of geology is that geologists often work with very long time scales; whereas, life-science specialists deal with much shorter time scales. In actuality, however, geological processes occur over a variety of temporal and spatial scales. At one end of the temporal spectrum lie the processes that occur over millions of years, such as the rising of a mountain range or creation of an ocean basin. At the other end lie the processes that occur virtually instantaneously (and often catastrophically) such as floods, landslides, and earthquakes. Between these extremes is the constant, continuous evolution of a landscape over days, months, and years. Examples of these are shoreline movement, river transport of sediment, soil formation, and cave development.

Geological processes are as diverse spatially as they are temporally. The absorption of chemical elements by sediment particles may be the key process in determining groundwater chemistries. This process occurs at the microscopic level. In contrast, the geothermal activity at Yellowstone or Lassen Volcanic national parks is related to the movement of tectonic plates at a global scale.

Geological processes that most directly impact biological processes include: stream and groundwater flow, weathering and mass wasting (e.g., landslides, rockfalls), earthquakes, volcanic phenomena (e.g., eruptions, hot springs), and variation in physical and biogeochemical attributes of soils. These processes collectively operate on a variety of time scales, and it is possible for all of these processes to be operating simultaneously in a single park. For example, minor earthquakes usually accompany eruptions in Hawaii Volcano National Park, and the overall event can include landslides, stream diversion by lava flows, and buildup of topography when the lava flows solidify. These processes destroy some habitats while creating others, and introduce new substrates for early successional stages, thus maintaining habitats for early successional species (Parrish and Turner, 2001).

Even seemingly static geological resources contribute to ecosystem mosaics and biodiversity. For example, in Grand Canyon National Park, the nesting sites of spotted owls are restricted to ledges formed in a specific rock layer, the Hermit Shale. Similarly, vegetation distributions in Canyonlands National Park respond to variation in surface soil textures and elemental content. Thus, management of the nesting sites of threatened species and unique native plant habitats requires knowledge of the geological substrate. Identifying that a rock layer is important to an owl species indicates the need for integrated research. An example of floral dependence on geology is the Winkler's cactus, which grows only on the white, powdery soil and pebbles eroded from part of the Morrison Formation in Canyonlands National Park. In this case, not only is the distribution of the rock layer itself important to the plant, but the erosion products are quite fragile, requiring management of both the plant and its delicate habitat (Parrish and Turner, 2001). This same type of abiotic-biotic pattern repeats itself across the entire Colorado Plateau, a region recognized for its high frequency of plant endemism primarily because of the evolutionary constraints posed by extensive exposures of raw geologic substrates (Welsh et al., 1993).

Abiotic ecosystem components, encompassed by the matrix sciences, play central roles in shaping the distribution and dynamics of biotic systems. Nutrient constraints; water availability; disturbances in the form of landslides, floods, droughts, and eolian processes all act to constrain the composition, structure, and productivity of the terrestrial biosphere. These processes also influence the distribution of individual plant and animal species across the landscape and condition the responses of ecosystems to environmental change. In present-day ecosystems, there is tremendous variability across landscapes and through time in the ways that ecosystems respond to changes in species, climatic patterns, and land use; this variability is poorly understood. For example, how will ecosystems, and the goods and services they provide, be differentially affected by the numerous interacting components of global change: increased temperatures and CO_2 concentrations, altered precipitation patterns, and greater frequencies of extreme climatic episodes? This question can no longer be left to the future (McCarty, 2001; Hannah et al., 2002). From a management perspective it is crucial to identify and predict the spatial and temporal variation in both ecological vulnerabilities and services. Improved understanding of this variability would allow for more efficient, cost-effective, and sustainable use of natural resources. One of the primary hindrances to this understanding is the lack of integrative science that could facilitate ecological forecasting. In the face of rapid environmental changes, successful resource management cannot be accomplished without integrating the abiotic matrix sciences with the more-familiar biotic sciences.

These are exciting and stressful times for resource managers, as attempts to counter threats to cherished places and species are made. Disciplinary boundaries, although essential for some purely scientific tasks, are an impediment to understanding complicated issues such as preservation of ecosystems. Human attitudes and past human influences on natural systems are crucial elements in understanding what is happening and what options are available (Ludwig, 2001).

Cited References

Christensen, N.L., Bartuska, A.M., Brown, J.H., Carpenter, S., D'Antonio, C.M., Francis, R., Franklin, J.F., MacMahon, J.A., Noss, R.F., Parsons, D.J., Peterson, C.H., Turner, M.G., and Woodmansee, R. G., 1996, The report of the Ecological Society of America Committee on the scientific basis for ecosystem management: Ecological Applications, v. 6, p. 665-691.

Hannah, L., Midgley, G.F., Lovejoy, T., Bond, W.J., Bush, M., Lovett, J.C., Scott, D., and Woodward, F.I., 2002, Conservation of biodiversity in a changing climate: Conservation Biology, v. 16, p. 264-268.

Ludwig, D., 2001, Crisis and transformation: Conservation Ecology, v. 5, no. 1, article 11. [online] URL: http://www.consecol.org/vol5/iss1/art11

McCarty, J.P., 2001, Ecological consequences of recent climate change: Conservation Biology, v. 15, p. 320-331.

Parrish, J. and Turner, C., 2001, [unpublished] Life on Earth—the biogeological interface.

Pickett, S.T.A., Parker, V.T., and Fiedler, P.L., 1992, The new paradigm in ecology—implications for conservation above the species level, *in* Fiedler, P.L. and Jain, S.K., eds., Conservation biology—the theory and practice of nature conservation, preservation, and management: New York, Chapman & Hall, p. 65-88.

Rowe, J. S., 2001, In search of intelligent life: Conservation Ecology v. 5, no. 2, response 3. [online] URL: http://www.consecol.org/vol5/iss2/resp3

Sauier, R.T., 1994, Geomorphology and Quaternary geologic history of the Lower Mississippi Valley, *in* report prepared for the U.S. Army Corps of Engineers Waterways Experiment Station, I: 53-54: Vicksburg, Mississippi.

Smith, V., 1998, Development of a priority area restoration and protection plan for a moderately sized agricultural watershed in southwestern Wisconsin, *in* Rivers—the future frontier, Proceedings of the 1998 Symposium April 28 to May 3, 1998: River Management Society, Anchorage, Alaska.

Steen, M., 1999, Effects of historic river alteration on Fremont cottonwood regeneration—a case study of the Virgin River in Zion National Park, Utah: Madison, University of Wisconsin, Environmental Studies, Master's proposal.

Swanson, F.J., Kratz, T. K., Caine, N., and Woodmansee, R.G., 1988, Landform effects on ecosystem patterns and processes: Bioscience, v. 38, p. 92-98.

Vitousek, P.M., 1994, Factors controlling ecosystem structure and function, *in* Amundson, R.G., Harden, J.W., and Singer, M. J., eds., Factors of soil formation—a fiftieth anniversary retrospective, SSSA special publication no. 33: Madison, Wisconsin, Soil Science Society of America, p. 87-97.

Welsh, S.L., Atwood, N.D., Goodrich, S., and Higgins, L. C., eds., 1993, A Utah flora, Second edition: Provo, Utah, Brigham Young University, 986 p.

Appendix E: Park Geological Setting

The Lewis Overthrust of Waterton-Glacier International Peace Park provides scientists with dynamics of geologic processes that are going on today in other parts of the world, such as the Andes and the Himalaya Mountains. Because of the high degree of preservation of the original rock characteristics, the recent glacial sculpturing of the rocks, and the access by roads and trails, this major geologic structure in the park is available for study by scientists from around the world.

The Lewis Overthrust began 170 million years ago, when a collision of Earth's crustal plates elevated numerous mountain chains and formed the Ancestral Rocky Mountains. Ever-increasing stresses near the end of this great event shoved a huge rock wedge, several miles thick and several hundred miles wide, eastward more than 50 miles. Large masses of relatively stronger rocks were shoved over softer and more easily deformable rocks. Erosion stripped away the upper part of the original rock wedge and exposed the rocks and structures visible in the park today. Rarely have rocks of such ancient age been thrust over rocks that are so much younger. The overlying Precambrian (Proterozoic) rocks are over 1,400 million years older than the underlying Cretaceous age rocks. Thus, the Lewis Overthrust is significant as a structural feature, for the extent of lateral displacement (up to 80 kilometers), and because it has exposed ancient sediments possessing an unparalleled degree of preservation.

Of particular scenic and geologic note is Chief Mountain, a spectacular monolith towering above the prairie along the eastern margin of Waterton-Glacier International Peace Park. Chief Mountain is an erosionally isolated remnant of the eastern edge of the upper plate of the Lewis Overthrust—a feature known as a klippa ranking with the Matterhorn as an example of this structural and erosional phenomenon.

Most of the rocks exposed in the park are sedimentary rocks of the Belt Series, of Mesoproterozoic age, which were deposited from around 1,600 to 800 million years ago. Rocks of that age in other parts of the world have been greatly altered by mountain-building processes and no longer exhibit their original characteristics. These virtually unaltered Proterozoic rocks are unique in that they have preserved the subtle features of sedimentation, such as milimetric lamination, ripple marks, mud cracks, salt-crystal casts, raindrop impressions, oolites, six species of fossil algae, mudchip breccias, and many other bedding characteristics. These Proterozoic sedimentary rocks, while outcropping over an area extending from southern Montana to southern British Columbia, are most impressively exposed in the park. Due to the extreme relief and unexcelled exposures, over 2,100 meters of stratigraphic thickness is exposed for scientific examination. These features plus their chemical characteristics make the Proterozoic sediments of Waterton-Glacier International Peace Park unique for studying the physical and chemical conditions that existed on Earth over a billion years ago. Several of the sedimentary rock layers described above, contain fossils called stromatolites. They were colonial organisms of blue-green algae that lived in warm shallow seas marginal to ancient lands. Six species representing three genera of stromatolites are preserved in the ancient sediments of the park. The Appekunny Formation contains bedding structures, which have being classified as the remains of the possibly oldest metazoan on Earth. Pushing the limits of the origin of the metazoans one billion years back.

The glaciers in Glacier National Park today are all geologically new having formed in the last few thousand years. Presently, all the glaciers in the park are shrinking. More snow melts each summer than accumulates each winter. As the climate changed over the last two million years, glaciers formed and melted away several times. During the Great Ice Age, or Pleistocene, the park's major valleys were filled with glacial ice over a mile in thickness, carving the outstanding glacial topography seen today. Textbook examples of glacially carved landforms are on display in the park: horns, cirques, arêtes, hanging valleys, and moraines.

A wide variety of landslide types exist in the park, ranging from slow-moving slumps in glacial till to potentially catastrophic, high-speed sturzstroms (rock avalanches). Hazardous landslides in the parks include rockfalls, rockfall avalanches, debris flows, and snow avalanches. Several dozen historical incidents of rockfalls along Going-to-the-Sun Road, US Highway 2, and the Many Glacier Road have produced injuries and fatalities. Both park visitors and employees have been injured by rockfalls. Rockfalls in the park are triggered by freeze-thaw activity and precipitation.

Rockfall avalanches (sturzstrom) have occurred in several locations along the Lewis Overthrust Fault during the 20th century; fortunately, no injuries have yet been recorded from these high-speed landslides, but their occurrence has caused temporary road and trail closures. Rockfall avalanches have also impounded two potentially hazardous landslide-dammed lakes (in 1910 and 1946) in the Otatso Creek drainage in the northeastern corner of the park. Debris flows in Glacier National Park are widespread, with literally thousands of debris-flow deposits distributed throughout the park. Debris flows produce frequent threats to visitors and park employees along Going-to-the-Sun Road. During the evening of 28 July 1998, a strong frontal storm brought drenching rains to the area, and numerous debris flows were triggered throughout the Park. Three flows crossed Going-to-the-Sun Road, trapping cars between the flows and exposing their occupants to the possibility of further flows. National Park Service personnel quickly rescued the occupants from the trapped vehicles, but it took over 24 hours for the debris-flow deposits (in excess of 20-40 tons of sediment per deposit) to be cleared from the road, thus temporarily shutting down Going-to-the-Sun Road during the height of the tourist season.

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References

http://www.nps.gov/glac/home.htm

Appendix C: Park Setting

The 49th parallel separates the United States and Canada on paper, but it does not delineate distributions of plants, animals, soils, or rocks. Waterton-Glacier International Peace Park is not only a meeting place for plants, wildlife, rocks, and soil, but also for people. Although Glacier National Park and Waterton Lakes National Park were set aside separately, Canada and the United States have shared this mountain wilderness for 70 years. The joining together of the two parks to form Waterton-Glacier International Peace Park came through the grass-roots efforts of Rotary International. In 1931, members of the Rotary Clubs of Alberta and Montana suggested joining the two parks as a symbol of the peace and friendship between the two countries. In 1932, the United States and Canadian governments voted to designate the parks as Waterton-Glacier International Peace Park, the world's first. The International Peace Park symbolizes the peace and goodwill between the United States and Canada as exemplified by the world's longest undefended border. More recently the parks have received two other international honors: Biosphere Reserves in 1976 and a World Heritage Site in 1995. This international recognition highlights the importance of this area, not just to the United States and Canada, but to the entire world.

Recent archaeological surveys have found evidence of human use dating back over 10,000 years. These people may have been the ancestors of tribes that live in the area today. By the time the first European explorers came to this region, several different tribes inhabited the area. The Blackfeet Indians controlled the vast prairies east of the mountains. The Salish and Kootenai Indians lived and hunted in the western valleys. They also traveled east of the mountains to hunt buffalo.

Glacier National Park regional context

In the early 1800s, French, English, and Spanish trappers came in search of beaver. In 1806, the Lewis and Clark Expedition came within 50 miles of the area that is now the park. As the number of people moving west steadily increased, the Blackfeet, Salish, and Kootenai were forced onto reservations. The Blackfeet Reservation adjoins the east side of the park. The Salish and Kootenai reservation is southwest of the park. The Blackfeet Indian Reservation is made up of 1.5 million acres and is located in the northwestern part of Montana, and includes most of Glacier County. On the north it borders the Canadian Province of Alberta. On the west it shares a border with Glacier National Park. The Blackfeet Tribal Council is the governing body within the exterior boundaries of the Blackfeet Indian Reservation. The Blackfeet Tribe, in its relationship with the federal government as a "domestic sovereign" Indian nation, is recognized as a nation within a nation through treaties, agreements, laws, and executive orders.

The railroad over Marias Pass was completed in 1891. The completion of the Great Northern Railway allowed more people to enter the area. Homesteaders settled in the valleys west of Marias Pass, and soon small towns developed. Facilities for tourists also started to spring up. The park contains over 350 structures listed on the National Register of Historic Sites and six National Historic Landmarks.

Under pressure from miners, the mountains east of the Continental Divide were acquired in 1895 from the Blackfeet. Miners came searching for copper and gold. They hoped to strike it rich, but no large copper or gold deposits were ever located. Although the mining boom lasted only a few years, abandoned mine lands are still found in several places in the park.

Alpine scenery, turquoise lakes, and Rocky Mountain wildlife characterize the park. Rugged peaks rise far above rounded valleys, the work of Ice Age glaciers. Over 700 miles of hiking trails traverse glacially sculpted U-shaped valleys, horn-shaped peaks, and sheer-walled basins. The Going-to-the-Sun Road is one of the most scenic roads in North America. The construction of the road forever changed the way visitors would experience the park. Visitors now drive over sections of the park that previously had taken days on horseback to see. The construction of the Going-to-the-Sun Road was a huge undertaking. Even today, visitors to the park marvel at how such a road could have been built. The final section of the Going-to-the-Sun Road, over Logan Pass, was completed in 1932 after 11 years of work. The road is considered an engineering feat and is a National Historic Landmark.

The jagged crest of the Continental Divide is the backbone of the park and splits it into two climatic regions. West of the Continental Divide, Pacific fronts bring heavy precipitation and moderate temperatures. To the east, dry continental air coupled with desiccating winds creates a colder, more severe environment. Weather patterns and topography have come together to create a land of sharp contrasts and diversity.

Moist areas west of the Continental Divide give rise to cedar-hemlock forests; spruce-fir forests cover drier slopes. Vivid alpine meadows spread over the high country, and rich prairies reach into the plains. Grizzly bear and wolves, symbols of wilderness, roam free on this landscape, along with black bears, bighorn sheep, and mountain goats.

Waterton Lakes National Park regional context

Waterton Lakes National Park is in the southwestern corner of Alberta, where the "prairie meets the mountains." It is one of a system of protected heritage areas administered by the Department of Canadian Heritage under the National Parks Act 1988. As such, it protects an example of physical and biotic themes representative of the Rocky Mountains Natural Region.

Waterton Lakes National Park—at 525 km^2—is a small portion of the international Crown of the Continent Ecosystem. The Crown of the Continent is an area strongly influenced by Pacific Maritime weather systems which flow inland, nearly unimpeded, across the Columbia Plateau before spilling across the narrowest point in the Rocky Mountain chain. This Pacific Maritime influence is so pronounced and persistent that it has resulted in the spread of plants and animals more commonly associated with the Pacific Northwest across the Continental Divide, and produced unique vegetation assemblages not found farther north or south in the Rockies. In Waterton Lakes National Park and Glacier National Park to the south, elements of the prairie biota of North America's interior plains encounter and mingle with elements of the Pacific Northwest and Rocky Mountain biotas.

Waterton Lakes National Park itself consists of only the extreme headwaters of two short rivers—the Waterton and Belly—that drain east from the Continental Divide into the

Saskatchewan River system. Because of the Lewis Overthrust, which displaced a Precambrian sedimentary mass eastward 40 to 50 kilometres, there is an abrupt transition from high mountains to undulating plains in Waterton Lakes National Park and, with the exception of a large alluvial fan (Blakiston Creek) and morainal complex lying to the north of this fan, boundary changes to the park in the past have excluded most lowland areas from the park.

Major periods of access development coincided with park development, especially during the 1930s and 1940s when the Chief Mountain Highway, Cameron Lake Parkway, and Red Rock Parkway were constructed or improved. Roads opened up the surrounding area during development of the Shell-Waterton gas field in the 1960s and 1970s and during the pine-beetle salvage logging in the mid 1980s. Recreational use of the national park peaked in the 1970s and has declined somewhat since then. Off-road vehicle use in areas around the park increased in the 1980s. In 1996 the Alberta government instituted a voluntary access management plan to restrict uncontrolled off-road vehicle use north of the park, but it met with mixed success. Some reduction in backcountry activity resulted from a major flood event in June 1995 that washed out some access trails and stream crossings in the Flathead and Castle River watersheds.

The provinces of Alberta and British Columbia manage the areas within the Rocky Mountains north, east, and west of Waterton Lakes National Park under a multiple-use management regime that has provided for extensive oil, gas, forestry, and ranching use and development. The undulating plains and narrow band of foothills lying north and east of the park is primarily in private ownership, and the predominant economic use is livestock ranching, although small recreational holdings have increased in the past decade. The Blood Tribe administers a timber reserve in the Belly River valley, which includes important wildlife habitat and aquatic resources and contains no permanent residences. The much larger Blood Indian Reserve 148 northeast of the park, is heavily settled and used primarily for crop and livestock agriculture.

The regional economy is based on agriculture and resource development. Some ranches are now in their fourth generation of family ownership. Traditional aboriginal use extends back many more generations. Mormon settlers colonized the Cardston area in the late 1800s and now have established a strong and cohesive agricultural community east of the Waterton River and north of the park, including significant amounts of land under irrigation with water diverted from the Belly and Waterton rivers. West of the Waterton River, there is more diversity in cultural and religious origins and less irrigation agriculture. The Shell-Waterton gas field brought in many families that live in Pincher Creek or on farms and acreages in the region. More recently, recreational second homes, land speculation, service-sector small businesses, and retirees have contributed to a trend towards increasing subdivision and sale of small acreages throughout the region. Most regional residents take pride in the quality of the natural environment.

References

Ahlenslager, K.A., 1999 (fifth printing), Glacier—the story behind the scenery: Las Vegas, Nevada, K.C. Publications, Inc., 48 p.

Harris, A.G. and Tuttle, E., 1990 (fourth edition), Waterton-Glacier International Peace Park, *in* Geology of National Parks: Dubuque, Iowa, Kendall/Hunt Publishing Company, p. 279-288.

Parks Canada, 1998, An ecosystem conservation plan for Waterton Lakes National Park: Waterton Lakes National Park, Alberta, p. 4-5.

Web addresses

http://parkscanada.pch.gc.ca/parks/alberta/waterton_lakes/Waterton_lakes_e.htm

http://www.nps.gov/glac/home.htm

Appendix G: Compilation of Notes taken during Scoping Session

August 22, 2002

Dust storm magnitude, duration, and frequency

Issues
- Visibility in the park is declining
- Dust storms are contributing factor (influence) to visibility and air quality

Human influences
- Agricultural practices are a human influence on source of dust storms, but not on duration or frequency
- Other human influences on air quality: reservoir draw-down, coal power plants in Alberta

Management significance
- Since managers are not able to control this phenomenon, this is not a pressing management concern

Monitoring
- Include monitoring of dust storms with current monitoring or air quality in general, as a cause to the decline of air quality and visibility

Research (if air quality declines)
- Analysis of particles (size and composition) to determine source area
- This type of data-collection is being performed in Olympic National Park
- Question: What impact are western Washington's agricultural practices having on the park?

Wind erosion (transport and deposition)

NOTE: The group chose to add "transport and deposition" to include the full geomorphic process.

Issues
- "Cobble dunes" are present in park, which indicates presence of severe winds
- Fines have been eliminated from surface sediments by wind erosion; what remains is a lag (armored) surface, upon which plants have difficulty establishing
- Example of locations where wind erosion is prevalent are, in general, alpine areas and arid settings; specifically, Sun Point and Prince of Wales Hotel area
- Significant for snow transport, especially in the nourishing of cirque glaciers/snow fields

Human influence
- Current human influences are localized, e.g., foot traffic/trail erosion at Logan Pass and Sun Point
- Past human influences: horse trails (groups of 50-100 horses on passes)

- Especially bad on rocky areas and areas overlain by the Mazama tuff

Management significance

- Managers focus on localized “nodes” where erosion is enhanced by wind, such as higher elevation-high use areas, where soil loss occurs or trails are heavily eroded
- No inventory or monitoring is currently being performed
- The primary concern for managers is trail erosion, of which wind erosion plays a role along with water and foot and stock traffic
- Boardwalk on trail at Logan Pass to minimize impacts
- Some trails are being naturally reclaimed by restricting or diverting foot traffic

Research

- How significant is wind erosion overall? Separate impacts of wind erosion from other erosion-causing agents. Extrapolate over ecosystem-wide impact as a geological agent/process. Then evaluate using inventory and monitoring methods, such as repeated site-specific inventories using repeat photography and GPS surveys.
- Wind is an important process to tree development at tree line; current monitoring of m^2 plots

Wetlands extent, structure, and hydrology

Issues

- Beavers are considered an important factors in the creation of wetlands
- Beaver influence extent, structure, and hydrology of wetlands in the park. Beaver influence extent, which can be tracked on air photos.
- Beaver create a warm-water environment, which affects brook trout (an non-native species)—the point of this statement is unclear. The ponds themselves are not the cause of infestation; they have been introduced and are attracted to this type of habitat (J. Potter, personal communication, 10/16/02)
- Beaver population was drastically lowered at the turn of the 20th Century because of hunting; last 50 years there has been little change in beaver population
- Glacial retreat influence wetlands: provide increased sediment to wetlands because of glacial retreat, also formation of small lakes in areas of retreat
- Glacial retreat creating new wetlands vs. filling in wetlands (and lakes) with sediment
- Change in type of precipitation (snow vs. rain) affects wetlands
- Wetlands are prime locations for rare plants; therefore, important for biodiversity
- 98% of species rely on wetlands in one way or another
- Wetlands are extremely dynamic: 50% change in areal extent has been noted from year to year
- Small lakes on the prairies dry up under dry conditions

Human influence

- Trapping of beaver (historic influence)
- Many roads (and backcountry trails) intersect wetlands, influencing extent, structure, and hydrology
- Human impacts are relatively low (e.g., no dewatering of wetlands); most changes are natural

Management significance

- Wetlands are a keystone feature in the park
- Law mandates that managers always consider wetlands in management decisions (in the US); in Canada, it is not legally mandated, but managers recognize the significance of wetlands and their prevalence in human-use corridors

Inventory

- Many different kinds of wetlands: fens, bogs (i.e., sphagnum wetlands), nutrified lakes, swamps, etc.
- Park has gross inventory that used USDA Forest Service system
- Also in 1995, US Fish and Wildlife performed mapping of wetlands using selective ground-truthing during amphibian study
- Need more accuracy and consistent descriptions. First cut on inventory would be to validate Fish and Wildlife classification and refine delineation. In addition, ground-truthing is needed, then remote sensing. Problems with remote sensing are expense and that tree canopy may hide some wetlands.
- Use aerial photos (on a decadal scale) to inventory wetlands—changes over time can be tracked, can also use satellite imagery
- Questions: What to focus on in inventory? Vegetation mapping, soil mapping, geoindicator with other bioindicators? What would you measure?
- Question: Are wetlands getting drier? Wetter?
- Question: What types of insects exist in wetlands? Sample is needed.
- Assessment needed of types of riparian wetlands in park, other than those influenced by beaver
- Sediment cores can show successional history of wetlands, e.g., climate-driven changes vs. beaver. Perform pollen and charcoal analyses on cores. Concern: coring can be very visible because of platforms. Researchers and park staff would need to work together in educating visitors. Ice platforms (in winter) are a possibility—less impact and less visible in winter (lower visitation time).

Monitoring

- Question: Because of diversity of kinds of wetlands, what should be monitored?
- Question: What changes have occurred in the past? Are they systematic?

Research

- Study of bogs in Glacier NP performed by Cathy Whitlock (University of Oregon) to determine Holocene changes of climate, used Mount Mazama ash as reference
- Question: What is the affect on fire on wetlands? Observations have been made of changes in watertable in small wetlands after fires. These observations have not been quantified, however.
- Question: Where do wetlands exists and to what extent from year to year?
- Question: What are past impacts of glacier fluctuations on wetlands?

Inventory, monitoring, and research summary

- Main question: What does the park need to know? This question needs to be formulated and narrowed because so much could be studied and discovered.
- Park needs good baseline inventory
- Look at historical record (use sequential historic air photos and sediment cores)
- Monitoring is needed to determine future change
- If significant changes are detected, what is causing it?
- Monitoring of wetlands could be multi-faceted, including vascular plants, water chemistry
- Wetland studies suggest opportunities for integrated studies and collaboration

Contacts

- Integrated research: Kathy Tonnesson (CESU, University of Montana)
- Marlow Pellatt (Parks Canada, Vancouver)
- Randy Schumann (USGS, Denver)

References

Hansen, H.P., 1948, Postglacial forests of the Glacier National Park region: Ecology, v. 29, p. 146-152.
Examines undated cores from Johns Lake and Fish Lake in the Lake McDonald drainage.

Elias, S.A., 1988, Climatic significance of Late Pleistocene insect fossils from Marias Pass, Montana: Canadian Journal of Earth Sciences, v. 25, p. 922-926.
Insect fossils from an unspecified lake at Marias Pass, along Glacier's southern boundary.

Carrara, P.E., 1995, A 12,000 year radiocarbon date of deglaciation from the Continental Divide of northwestern Montana: Canadian Journal of Earth Sciences, v. 32, p. 1203-1307.
Radiocarbon dating of wood fragment from lake sediments exposed in a roadcut, perhaps also where Elias' fossils were exposed(?)

Carrara, P.E., 1989, Late Quaternary glacial and vegetative history of the Glacier National Park region, Montana: USGS Bulletin 1902, 64pp.
Lots of coring of bogs on the west side, in the Bowman Lake area, Lake McDonald area; also in the Marias Pass area, and the Kootenai Lakes area immediately south of Waterton Lake. Mostly non-pollen stratigraphy, with volcanic ashes in the bog and lake cores.

Karst

Issues

- Lack of inventory (systematic survey) of cave resources
- Seven or eight caves that people go through; in four, the physical features have been mapped, e.g., Algo Cave
- Protection—NPS can't reveal because caves are considered fragile resources. Park keeps caves closed where possible. Glacier NP has gated one cave for safety and resource protection.
- Many local cavers have information on the number and extent of caves in the park but do not want to share it with others for fear of closures of caves

- Karst terrain is much more encompassing than caves in the park; karst forms in the Helena Formation
- Example of karst: there are many perched lakes without outlets in the Helena Formation
- Importance for species diversity. For example, limestone features have been identified as critical to Threatened and Endangered Species in Canadian parks (David Welch).
- No record of sinkholes opening

Human influence
- Not knowing the amount and extent of karst makes it is difficult to say what influence humans are having on it
- No known significant human impact on the known caves

Management significance
- No current mapping in progress
- Not managing, except for fencing to keep people out

Inventory
- What are the changing conditions in caves?
- Use local cavers to perform inventory—they have the expertise and may do it for free
- There is a “grotto” (National Speleological Society group) in Missoula
- Local caving groups (Whitefish and Browning) have observed changes in caves
- Glacier NP knows number and location of significant caves but not their resources

Contact
- Ron Kerbo, Cave Specialist, NPS Geologic Resources Division, Lakewood, Colorado, ron_kerbo@nps.gov, 303-969-2097.

Seismicity

Issues
- Monitoring program run by Montana Bureau of Mines and Geology. Currently MBMG has 34 stations, mostly in the western part of the State. Additionally, they receive data from stations in bordering areas, including the Waterton station that Cyndi mentioned. The latter, in conjunction with other stations that we operate, allows MBMG to locate quakes in the vicinity of Glacier NP, but resolution is poor and the smaller quakes go undetected. Much better detection and resolution could be obtained with 1 or 2 stations inside the park. MBMG data feed into the national USGS system in Colorado. Detected quakes are automatically analyzed and information is posted on MBMG’s Web site within minutes: http://mbmgquake.mtech.edu/.
- Contact: Mike Stickney, Manager, Earthquake Studies Office, 406-496-4332, mstickney@mtech.edu.
- Each station costs $15,000-$25,000 plus nominal upkeep of station
- Real-time data available on Web (sent to national Earthquake Information Centers)
- Up to magnitude 4.5 earthquakes recorded in area; risk depends upon the occurrence of a significant seismic event, but the park has not had a damaging earthquake in modern history

- May be historic correlation of earthquakes to debris flow and rockfall

Management significance
- Park does not consider earthquake activity a significant management issue; important when/if a major seismic event occurs, but otherwise not something that can be prevented.
- As for seismic monitoring, as long as things are quiet it is not important, but given the topography and geology of the Park, seismicity will be front page if a large event should occur (E. Deal, personal communication, 9/17/02)

Monitoring
- Currently good coverage and historic records for area (note contrast in recommendations following personal communication with Ed Deal)
- Seismograph in Waterton Lakes

Groundwater level and Groundwater quality

Issues
- The Montana Bureau of Mines and Geology has a statewide groundwater program. Park staff is asked to share/submit data to Montana Bureau of Mines and Geology (MGMG). Montana Bureau of Mines and Geology needs information on high mountain areas, which the park could provide. The information will be to characterize the aquifers in Montana. It will be made available to the public via Montana Bureau of Mines and Geology's Web site: www.mbmg.mtech.edu.
- Contact: Tom Patton, Manager, Ground Water Assessment Program, 406-496-4153, tpatton@mtech.edu
- Users entering the Ground Water Information Center Database (GWIC) must provide a password (of their own choosing). After that, it's easy. Apparently, the 170,000 or so wells in the database do not include any in Glacier NP, but it could if the data are supplied to MBMG. An accurate well location is critical for any data to be useful.
- There is groundwater information available on the Internet—a large database; also pesticide and herbicide information available
- Intensive study Flathead to be published in the fall, 2002. Contact: Celestine Dunn, Department on Environmental Quality
- Concern over water supply, especially later in the summer. For example, Glacier supplies water to inholders at Lake McDonald. GLAC supplies inholders in the vicinity of Lake McDonald Hotel with water from park system at Rubideau Spring. Inholders farther around the head of the lake are on their own (J. Potter, personal communication, 10/16/02)

Importance to ecosystem
- Waterton Lakes NP has developed corridor in alluvial valley, groundwater-surface water interactions
- It appears that most, if not all, of the park's wells are included in the Montana Bureau of Mines database. I did a quick check and found the wells at Lake McDonald Lodge, Many Glacier, Two Medicine, Apgar included. I didn't check for all the other locations in the park. But everywhere that I checked, I found wells in the database. There is a large area of the park

with no wells (or any other infrastructure) and therefore no well info for those areas. (L. Martin, personal communication, 9/5/02)

Groundwater level

Human influence

- Park provides water to West Glacier
- No large-scale irrigation in area
- Small consumptive use
- Typically groundwater is quite deep; develop water supply from springs.
- Correction: The above statement that groundwater is quite deep is not true. The bedrock formations are typically impermeable, except where fractured. The only real aquifers in the park are the alluvium associated with stream valleys. Groundwater levels are very shallow in the alluvium and the groundwater is interconnected with the surface water systems. I'm not sure what your point is regarding the second part of that bullet, "develop water supply from springs". I think that Roubideaux Spring is the only one that has been developed for a water supply (provides water for the Apgar, Headquarters, West Glacier areas). I believe that all other areas in the park either use surface water sources or have shallow wells into the alluvium. (L. Martin, personal communication, 9/5/02)

Management significance

- Park is at the headwaters, i.e., not downstream from other users
- There is lots of water and very little use

Monitoring

- McDonald Creek and North Fork confluence has 3-4 stations. Monitoring information is available on Nyack Creek. Park staff is asked to share/submit data to Montana Bureau of Mines and Geology. Montana Bureau of Mines and Geology needs information on high mountain areas.

Research

- Look at the overall budget with respect to climate change

Groundwater quality

Issues

- Management concerns: effects of sewage treatment (See notes from Field Trip Stop 1), salt application to roads, petrochemical residue in road runoff, pesticides, gasoline leaks from underground storage tanks
- Glacier NP has never permitted the use of salt on roads (J. Potter, personal communication, 9/26/02).
- Service stations in Waterton NP (2) and Glacier NP (1)
- Underground storage tank in Apgar—status unknown
- Inholders' septic systems

Management significance

- Confined to road corridors and developed areas
- Concern for protection
- Few areas have had groundwater quality problems, and those that have, have been mitigated

Inventory

- Current drilling to find out effects of pesticides in fescue grasslands (Two Dog Flats near St Mary)
- Update: Test wells at Two Dog Flats in 2002 showed no trace of herbicides in the water table (J. Potter, personal communication, 9/26/02)

Monitoring

- Park will monitor groundwater related to specific stressors, e.g., near sewage treatment in the future

Groundwater chemistry in the unsaturated zone

Issues

- Management concerns: effects of sewage treatment (See notes from Field Trip Stop 1), salt application to roads, petrochemical residue in road runoff, pesticides, gasoline leaks from underground storage tanks
- Glacier NP has never permitted the use of salt on roads (J. Potter, personal communication, 9/26/02)
- Contaminants move through unsaturated zone very quickly; either goes into the groundwater or soil, doesn't stay in unsaturated zone
- Low importance to ecosystem because of porous soils, narrow unsaturated zone, high water contribution

Management significance

- Since only 5% of Glacier National Park is developed (95% is proposed wilderness) and over 80% of Waterton Lakes National Park is recommended for wilderness declaration., human influence is low and only in developed/corridors with roads.
- Low significance—until there is a problem. If sites become contaminated, then significance becomes high because park must deal with these because of public health and legal mandates. There are no contaminated sites to currently deal with.

Soil quality

Issues

- Trampling alpine environments and trail erosion
- Reference: Hartley, E. 2000, Thirty-year monitoring of subalpine meadow vegetation following a 1967 trampling experiment at Logan Pass, Glacier National Park, Montana, *in* Cole, D.N., McCool, S.F., Borrie, W.T., O'Loughlin, J., eds., Wilderness science in a time of change conference—Volume 5: Wilderness ecosystems, threats, and management, 1999 May 23-27, Missoula, Montana, Proceedings RMRS-P-VOL-5: Ogden, Utah: USDA Forest Service, Rocky Mountain Research Station, Degradation of soil due to construction projects.

- Concerns: breakdown of soil structure, loss of function, harm to microrhiza, regional acid deposition, nitrate deposition (from urban pollution and fertilizers), mercury pathways
- What is the best way to reclaim soils? Park has attempted to sterilize soils and then build them up again prior to distribution; learned not to get too fancy with revegetating roadsides and trying to replicate diversity
- Reclamation of sites: introduction of new soil that may introduce exotic species (purchase soils that are certified weed free)
- Wide variety of soils
- Park staff has strong background in plants and works with NRCS, but need expertise on soils
- Would like to hire a soil scientist
- Estimated date for analysis of soil chemistry in GLAC is FY 04 (J. Potter, personal communication, 10/16/02)

Human influence
- Most of the alteration in soil quality is human induced
- Social trails and trail maintenance
- Borrow pits (historically became garbage pits, which attracted bears)
- Horse use is primarily a legacy issue in some areas and a problem in concession horse areas
- Popular lakes with multiple entry points
- Locating and constructing park facilities, e.g., Logan Pass Visitor Center
- Depletion of soils along roadsides: causes greater amount of noxious weeds, plowing causes compaction and depletion

Management significance
- High—basis for most terrestrial life forms.
- Spend time and resources dealing with soil quality and restoration issues

Inventory
- Both Waterton Lakes and Glacier have a soil survey
- Needs: interpretation of soil classification, derivative products, sampling to characterize locales (e.g., along road corridors)
- Soils mapping project to be completed in FY 2007 or 2008; scoping has been completed (Contact: Pete Biggam); actual work to be completed in 2004

Monitoring
- Monitoring of mercury deposition to begin next year (2003) on the west side of the park
- Recommendation: monitor change in carbon storage (once every 5 or 10 years). Use Douglas fir, which are very sensitive to CO_2, as an indicator species and early warning. Not too expensive.
- Contacts: Pete Biggam, Coordinator of NPS Soils Program, Lakewood, Colorado, and Randy Schumann, Chief Scientist, USGS, Denver
- Reference: Steve Running, University of Montana, vegetation dynamics model based on carbon dynamics fire model.

- Reference: Thompson, R.S., Hostetler, S.W., Bartlein, P.J., and Anderson, K.H., 1998, A strategy for assessing potential future changes in climate, hydrology, and vegetation in the western United States: U.S. Geological Survey Circular 1153, 20p.

Research
- Question: What soil properties help to stimulate the development of krumholz?—this may be more of a soil erosion issue for changing treeline in alpine areas

Recommendation
- Suggest that Vital Signs Network hire a soil scientist that could be shared among parks in network.

Soil and sediment erosion

Issues
- Construction projects result in pulses of sediment down stream; sediment resulting from the construction of the Going-to-the-Sun Road can be seen in the sediment column in McDonald Creek and in Lake McDonald
- Not all erosion is detrimental; often a natural process in many areas
- Poor design of facilities and sloppiness in clearing and construction
- See discussion of soil quality for additional information

Lake levels

Issues
- Lake levels fluctuate seasonally; don't know about long-term changes
- Shallow lakes are more indicative of lake level change vs. Lake McDonald (478 feet deep) has only fluctuated about a foot over the past decade
- Lake flooding affects townsite of Waterton, park access, and park facilities
- Lake ice: Winds are a factor on ice development on lakes on the east side of the park—this is significant for the arrival of (migrating) waterfowl
- Five lakes are monitored for date of first freeze and lake ice depth: (1) Lake McDonald, (2) St. Mary Lake, (3) Two Medicine Lake, (4) Bowman Lake, and (5) Kintla Lake

Inventory
- Good baseline study (1991), including good water quality sampling
- Lake ice: 9-year study records gradual freeze-up date, break-up date, and ice depth
- Lake ice depth captured via remote sensing

Monitoring
- Waterton Lake level is monitored
- Flooding forecasts are necessary
- Monitoring also takes place at Lake McDonald and Swiftcurrent Lake

Research

- Create “lake ice model” using existing data. Have data of years that large lakes have frozen over (recorded in Hungry Horse newspaper) and compare that information with meteorological data
- Question: Are small lakes being filled in with sediment?—can use radiometric dating techniques to address this question

Stream channel morphology

Issues

- Maintaining natural, alluvial processes while protecting facilities (roads, buildings) from channel changes
- Infrastructure built on alluvial fans
- Manipulation of creek to minimize flooding
- Need to maintain natural channel for thermal regime, which promote diversity of species, and nutrient cycling, which promotes productivity
- Channel migrates from valley wall to valley wall; therefore, large areal extent
- Morphology important to fisheries, riparian zones, macroinvertebrates

Human influence

- Relatively small issue park-wide, but locally important where there are facilities near streams and roads along streams
- Need more information on long-term changes in channel morphology with respect to human influences, e.g., Divide Creek
- Impacts on Divide Creek: (1) Channel has been manipulated by channelizing and removing gravels in an attempt to reduce flooding and protect private property and (2) roads (including Hwy. 89), Visitors Center, park facilities, commercial buildings have all been flooded, i.e., they are built in the floodplain

Management significance

- Dependant on flooding to get attention
- Channelizing causes loss of values of biodiversity
- Park boundary is based on location of rivers, i.e., North Fork and Middle Fork of the Flathead River)

Inventory

- Inventory of stream channel morphology; mapping and description of stream reaches [consistent with Montana Fish, Wildlife, and Parks (MtFWP) Mountain River Information System (MRIS)]. Selected rivers/streams (not comprehensive) that target developed area corridors. The information would be applicable to fisheries management and help predict impacts of park facilities. Contact: Richard Menicke, Geographer, Glacier NP.
- Need description of stream system, especially flood plains—can be done using hyperspectral mapping (aircraft mounted camera)
- Also mapping of floodplains, cutbanks (field work), and instream bathemetry (more difficult to do)

- Developed corridors need inventory
- Fish, Wildlife, and Parks agency has done an inventory for fisheries management—potential for the park to be included in this inventory
- Tom Pick (NRCS in Montana) is leading an effort of digital video camcorder (with GPS and using Red Hen software systems) photography of stream reaches for fisheries and riparian management. This information could be extrapolated to stream channel morphology and stream sediment storage and load. Contact: Tom Pick, tpick@mt.nrcs.usda.gov

Research
- Question: How much change has occurred because of human activities?
- Question: How do changes in channel morphology affect nutrient cycling, thermal diversity, and macroinvertebrates? Develop indices of biotic integrity using macroinvertebrates and fish

Stream sediment storage and load

NOTE: See stream channel morphology for related discussion of stream sediment storage and load.

Human influence
- Montana Highway Department puts pea-size gravel (argillite) onto Highway 2 during the winter. The snow is red along the highway because of this practice. The gravel becomes a sediment source to the streams.

Inventory and monitoring
- Data gained from turbidity studies would be useful baseline information to use as a comparison for when the road is reconstructed
- Monitoring will be conducted during road construction

Streamflow

Issues
- Studies show that there is the potential for more episodic events, not gentle increases but large events
- More than 30% of precipitation will come during events with greater than 2 inches of rainfall in 24 hours
- As glaciers retreat, streams become ephemeral
- Concern over water supply, especially later in the summer. For example, Waterton Lakes Golf Club draws water in Waterton Lakes.
- Streamflow has influence on visitor experience
- Streamflow affects riparian zones and wetlands

Management significance
- Flooding events will increase response and significance for managers

Monitoring
- Streamflow in selected basins with near-future loss of glaciers
- Stream gauging: USGS performs standard gauging on park boundary (Swiftcurrent)
- Gauging stations at St. Mary (2), Many Glacier (1), in McDonald watershed (6—main inputs all monitored)—these stations do not have stable funding
- In Waterton Lakes, Waterton River (1) and Belly River (1) both have gauging stations—these are operated by Alberta Environment
- Need skeletal monitoring of interior of park
- Need secure funding: pursue funding with USGS
- NPS Water Resources Division can assist with defining needs: locations, number, and cost; Contact: Larry Martin, Hydrogeologist, Ft. Collins, Colorado)
- Redwood National and State Park could serve as model—they have an established partnership with USGS for monitoring gauging stations

Research
- Question: What is the influence of woody debris on streamflow? (See Stop 2 in field trip notes, Appendix H)

Surface water quality

Issues
- Public heath issue
- Sediment influx from both natural and human influences
- Effects on fisheries
- Headwaters, therefore good water quality
- Very few incidences of giardia
- Some concerns for lake water quality with respect to septic systems
- Since water quality is so good, this is a good indicator of change in geological processes; minor changes are easily detectable

Human influence
- Herbicide and pesticide applications, e.g., for eradicating knapweed
- Localized situation: boating on St. Mary Lake and Waterton Lake, diesel fuel spills, wind causing a barge to capsize on St. Mary Lake, 50 gallons of diesel fuel spilled

Management significance
- Glacier NP is legally mandated to protect surface water quality under the Clean Water Act
- Surface water quality factors into management decisions and must be monitored, but the significance is elevated when there is a crisis

Inventory
- The "Baseline Water Quality Data Inventory and Analysis" for Glacier NP has not been completed (and could be a year); reporters/scientists are still in the data mining stages, so there is no preliminary data or assessment at this time (September 2002)

- Contact: Larry Martin, Hydrogeologist, WRD, Ft. Collins, Colorado, 970-225-3515, larry_martin@nps.gov

Monitoring
- Survey of baseline water quality data for lakes needs to be repeated
- Contact: Dan Fagre, Ecologist, USGS, Glacier NP, 406-888-7922, dan_fagre@usgs.gov

Frozen ground activity

Issues
- Solifluction terraces are not active, although modified by ice needles
- Seasonal freezing and thawing is active
- Patterned ground exists on a small scale
- Visible component of landscape for hikers; visual interest, although not active—relic landforms that are being reworked
- Adds to interest ecologically-speaking, but is not a central part of ecosystem function

Management significance
- Road break-up caused by seasonal frost action; this is a standard part of road maintenance

Monitoring
- Monitor degradation rates of frozen ground (linked to soil erosion)

Glacier fluctuations

Issues
- By 2030, glaciers will most likely be gone from the park
- Main impact will be to base streamflow and temperature for aquatic ecosystems
- Small areal extent overall, but individual glaciers have critical effect for basins they are in
- Ecosystems won't collapse when they disappear because of existence of seasonal snowpack, but systems will respond to greater seasonal variation (become "flashier"), have less late-season flow, and streams may become intermittent
- Glaciers are an icon of the park and, therefore, are a key element in interpretation and education
- Plants have already colonized in areas where glaciers have left and potential has been reached for total area and plant value, i.e., don't expect much future change

Management significance
- High significance with respect to public (visitors, legislators, etc.) information and education, since glaciers are a "charismatic geologic phenomenon"
- No active resource management

Inventory
- Inventory report of glaciers will be completed in June 2003; have already completed top 5 (largest) glaciers and are inventorying glaciers in order of size

- In general, inventory, monitoring, and research has been adequately for answering management decisions

- Additional notes (M. Demuth, personal communication, 9/27/02):

The report looks really good. Concentrating on the glaciological, snow avalanche and hydrology aspects, I would say things are covered-off very well. I would, however, encourage some form of additional systematic monitoring of glacier mass balance. For one thing, knowledge of seasonal mass balances (e.g., Summer and Winter) would shed light on the relative importance of the regime by which the glacier margins are fluctuating.... i.e., is glacier contraction due primarily to less nourishment in Winte rand/or more melt in Summer? This would also clearly assist in the interpretation of streamflow records. Second, having a glacier mass balance site this far south at this longitude would make an excellent contribution to the Global Terrestrial Network-Glacier (GTN-G) of World Meteorological Organization's (WMO) Global Climate Observing Network (GCOS). In Canada, we have been in the throws of improving our glacier-climate observing network and the gap analysis we performed suggested that a site this far south may provide a good analog for what could be expected further north in the Canadian Rocky Mountains over the next century.

It should be emphasized that glacier fluctuations are not only to be characterized by variations in the glacier margin positions (i.e., advance or retreat) and that this response, depending on glacier size, bed slope etc. may be the result of shifts in the mass balance regime at decadal, century, or millennial scales. It is the annual Summer and Winter mass balances that are the direct integrated measures of moisture and heat fluxes at the Earth surface.

For glaciers of the size remaining in Waterton-Glacier International Peace Park (WGIPP), it is clear that the majority (not all) are of the "glacier reservoir" type insofar as mass balance regime changes are manifested through changes in their thickness; a few are still dynamically active "glacier evacuators" insofar as mass balance regime shifts are manifested through changes in both thickness and area-wise extent. That being said, an effort could evolve that uses historical margin variation data to estimate what the secular mass balance has been. This would place current values (if they were to be measured) in some useful context.

Snow avalanches

Issues

- Snow avalanches are ubiquitous throughout park, e.g., in one basin (in Mount Gadin quadrangle) alone 29% is covered by snow-avalanche tracks
- Snow avalanches have come down into Waterton townsite
- Snow-avalanche tracks have great importance to ecosystem: productive environments, key habitat and serve as migration paths for grizzly and mountain goats, provide fuel breaks for fire, conduits for carbon and sediment from higher to lower elevations (including streams)
- Snow avalanches are a major landscape disturbance that shapes park ecosystem
- Snow avalanches primarily move snow (vs. rock debris)

Human influence

- Human use does not appear to be increasing the frequency of the release of snow avalanches

- Outside the park, snow avalanches "jump" over the snowsheds over the railroad, which predates the Highway 2, and land on the highway

Management significance

- Public safety issue, especially for winter recreationists
- Time and resources spent on forecasting of snow avalanches

Inventory

- Recommendation: Need to revisit the surficial geologic map (Paul Carrara) include all the path locations; present map does not show all the snow-avalanche paths
- Waterton town record of snow avalanches that have come into town

Monitoring

- Use repeat aerial photography to document the change of snow-avalanche paths (extent, locations) over time

Research

- Develop frequency of event analysis and historical record (e.g., from Waterton townsite record)—some attempt as this has been made using tree rings
- Contacts: David Butler (Southwest Texas State University) and George Malanson (University of Iowa)
- Compare east and west side cycles of snow avalanches
- Establish landscape-level disturbance agent and look at drivers; check against Pacific Decadal Oscillation climatic variations and see if tied to response of snow avalanches
- Question: Does snowfall level influence frequency?
- Questions: How much woody debris does snow avalanches deliver to the Highway 2 corridor? What is the relative amount of woody debris vs. rock material in snow avalanches?
- Possible use of Geoscientist-in-the-Park (GIP) funding for project to George Malanson and/or David Butler

Slope failure

Issues

- Agent in sediment transport to streams
- 1990 study showed that debris flows are changing (i.e., larger) with change in type of precipitation (i.e., increased rainfall events that are heavy and intense), used 1966 photos as a benchmark
- "Hotspots" for slope failure are the Cretaceous sediments on the east side of the park
- May be correlation of earthquakes to debris flow and rockfall
- Can use sediment cores to examine the frequency of slope failure by lake systems

Human influence

- Slumping along Many Glacier Road is a continuing maintenance issue ("headache")—the road undercuts the slope; in addition, there is saturation from reservoir

Inventory
- Waterton Lakes NP assessed cycles on rockfall using 300-year-old record

Monitoring
- Use repeat aerial photography for mapping features caused by slope failure
- Scanned digital photos from past aerial photos (currently in park archives) would be useful

Research
- Question: What is the relative importance of mass movement vs. stream transport?
- Question: Will an increase in rain events cause more landslides?
- Reference: Rapp, A., 1960, Recent development of mountain slopes in Karkevagge and surrounding northern Scandinavia: Geografisk Annaler, v. 42, p. 73-200.

Subsurface temperature regime

Issues
- May influence location of treeline
- Significance unknown for ecosystem and human influences
- Update: Gifford H. Miller (email: gmiller@colorado.edu) at the Institute for Arctic and Alpine Research (INSTAAR) in Boulder, Colorado was contacted regarding the significance of subsurface temperature regime for the park. There appears to not be much significance, and work is not currently being done in the park.
- For additional information, see the Web sites for the Global Terrestrial Network for Permafrost (GTN-P): http://sts.gsc.nrcan.gc.ca/gtnp/index.html and http://sts.gsc.nrcan.gc.ca/gtnp/English/bhinventory/us.htm.

Management significance
- Just not a “burning question” for park management

Sediment sequence and composition

Issues
- This is a “tool” not a process; it is of extreme importance for the park’s information base; it provides necessary background information and a context for ecosystem management decisions
- Records fire history; human disturbances (e.g., DDT, fertilizers, chemicals in fisheries); ash layers; isotopic signatures; sedimentation magnitude, frequency, rates—all of which would be useful information for park managers
- This is tremendously useful—the chemical, physical, and biological character of aquatic sediments can provide a finely resolvable record of environmental change, in which natural events may be clearly distinguishable from human inputs

Appendix H: Compilation of Notes taken during Field Trip

August 21, 2002

Stop 1: Confluence of McDonald and Middle Fork of the Flathead River

Topics: water supply, 1964 flood, sewage system, stream gauging network, Apgar infrastructure issues, septic line to Lodge, road slump, inholder septic systems

- 1964 Flood Rain on Snow Event. Backup water from the bridge to Apgar Village (built on terminal moraine)
- Sewage treatment currently in floodplain; in future will move sewage treatment to hillslope with new multi-million dollar facility; currently during the summer sewage is sprayed in fields and in winter held in ponds
- Issue of sewage/septic tanks from inholders along Lake McDonald
- Hyporheic zones important to stream aquatic life—described 24 new species in hyporheic zones
- Water rights issue: park currently supplies town of West Glacier with water; park accused of causing growth of the town; dug new line to spring, install new water system.
- Unsorted till in valley; relative risk to develop water source very high; easier/better to get water supply from the park because of concern for development of spring site
- Water issues: park discussed alternative water sources but would mean moving water from one drainage to another; also decided not to move water to generate power
- Golf Course—intensive pesticide and fertilizer use
- Department of Fish and Game introduce possum shrimp (scud) to Flathead Lake. Kokanee salmon run up stream to McDonald Creek to spawn. Kokanee compete with lake trout. At one time in the mid-1980s there were over 100,000 kokanee salmon spawning in streams. Salmon attract eagles and large predators. Shrimp prey on food source for salmon and within about four years crashed the kokanee salmon population (50 salmon in 1989).
- Ice build up on bridge—crush the bridge and park replaced the bridge
- Houses on floodplain, innundated numerous times; home owners attempted to influence the park to move the channel; Middle Fork Flathead Creek very dynamic
- Lake McDonald Creek—habitat for native fish, for example, mountain whitefish, bull trout (T&E), and cutthroat trout
- Lake trout introduced—park trying to reduce population of lake trout
- Development in floodplain—landowners use influence to change/straighten channel because natural change may mean decrease of land for some property owners

Stop 2: Moose Country–McDonald Creek

Topics: habitat complexity, log jams, channel changes, floodplain dynamics, biodiversity nodes, thermal complexity, road maintenance, Going-to-the-Sun Road reconstruction, sediment loads

- Road cuts off meander
- Wetlands area

- Borrow pit
- Extreme channel dynamics
- Noxious weeds an issue in the park
- Harlequin duck area—spend winter in Pacific, nest in GLAC in summer; highest concentration of Harlequin ducks in Montana; topped floating of the stream because of Harlequin ducks
- Area of high bear production too, although barren of fish
- Stream extremely dynamic and create upwelling cold water areas; create a thermally complex habitat and high biodiversity; macroinvertebrates are temperature sensitive; area functions naturally
- Only area where processes/geodynamics operating naturally so of great interest to Europeans
- Important for cycling nutrients and important to ecosystem
- 9 year of monitoring McDonald Creek; 6 gauging stations along creek—discharge, stream temperature, water chemistry, largest mountain watershed continuously monitored
- Channel Dynamics—snow dams, impacts by snow avalanches, fires
- Upwelling—hyporheic flow in paleo-channels which are zones of preferential flow, bedrock creates some nick points
- Snow-avalanche paths cleanest in 25 years
- 8-10 times creeks blocked by snow avalanches- outburst floods
- Bedrock control (with glacial influence with respect to erosion/scour) of "ribbon forest" distribution, i.e., no trees on outcrops; erosion to less steep slopes provides habitat for trees
- Geology features at stop: lateral moraine, argillite, U-shaped valley, Livingston Range-Lewis Range (northwest-southeast trending syncline)

Stop 3: Loop Road/Heaven's Peak Overlook

Topics: glaciation, retreating glaciers, snow avalanches, forest fire frequency and soil destabilization GTSR snow clearing, road maintenance issues, increase in extreme recreation (ice climbing, chute skiing, rock climbing)

- In 1850, 150 glaciers on map; currently <37 glaciers in park
- Carrara map shows 20 glaciers
- Glaciers movement—need 1 km of ice and 66 feet of ice to deform the lower ice layer
- Little Ice Age: in 1850, glaciers at maximum extent since Pleistocene
- Grinell Glacier >600 ft thick, by 1970s lost 300 feet and 1 km (only 10% of previous size in 1850)
- Glaciers once made up 99 km^2 on the landscape and now account for 27 km^2; 26 watersheds have no glaciers now
- Glaciers provide late summer water flow and regulate stream temperatures—significant consequences of loss of glaciers to aquatic ecosystems
- Plants colonize in areas of glacial retreat
- By 2030 it is predicted that all glaciers will be gone in the park; functionally without glaciers; since 1993 Grinelle Glacier lost 20 acres
- Now getting 33% less snowpack than in 1950s

- Snow/rain ratio favors rain and debris flow processes; change to rain deposition will change processes and the temporal distribution of processes; change in snow avalanches will change the treeline; snowpack suppresses tree establishment. Now getting trees rooting above the current treeline
- Big year for snow avalanches was 1979
- Every 5-7 years park gets snow avalanches big enough on lateral margins of path that trees are impacted (recorded in tree-ring record)
- Constructed rock walls along the Going to the Sun Road
- No longer a quarry in the park; no source to replace wall rock
- Plowing road is partial cause of the destruction of the road, i.e., snow avalanches slam against "uncovered" bridges and sidewalls
- Pressure to open the road earlier for visitors
- Road cuts have rock falls that occasionally hit cars and people
- Snow-avalanche hazard determines opening date of road, not amount of snow
- Rise in extreme sport in park, e.g., rapid climbing, ice climbing waterfalls, technical rock climbing in soft rock, squirt boats in waterfalls; no hang gliding or base jumping allowed, but does occur; recreationists moving from traditional areas where sports began, which had granitic (solid) rock, to Glacier where rock is sedimentary (less solid)
- Change in chemistry and form in wet deposition (change snow vs. rain); increase in acidity may affect bedrock and water chemistry of runoff
- Currently, relatively no change in chemistry, but see shift in snow vs. rain deposition
- Air resources division—deposition of toxic chemicals (dioxins, PCBs, mercury, etc.)
- Small quantities, long lasting chemicals in high elevation areas
- 6 parks in western U.S. (including Glacier NP)—methods development of POPs and mercury
- Issue—pollution can build up in tissue of biota

Drive By: Weeping Wall

- No source of water directly above; water moves along bedding plain/dip of Helena Formation

Photo Stop: Bird Woman Falls

Stop 4: Logan Pass

Topics: boardwalk, hydrology/rare plants/ amphibians/macroinvertebrates, climate monitoring, krummholz changes, tree-ring chronologies, grizzly bear nutrient cycling/disturbance, water supply/septic issues, PDO and long-term trends, soil reclamation and revegetation in fragile alpine area

- Trail—extensive erosion by visitors; park construct walkway; aesthetics is an issue
- Trampling study performed here (concern for soil and vegetation)
- 80% of visitors stop at Logan Pass
- Issues: human waste disposal (septic field in meadow, now trucking sewage, haven't had much luck with composting)
- Frequented by grizzly bears and mountain goats

- “Big Drift” (east of Logan Pass) can get up to 90 ft thick in heavy snow years; visitor center can be buried in snow
- Pacific Decadal Oscillation (sea surface temperatures of Pacific 20-30 year fluctuations); strong correlation, high PDO expect low snowfall; low PDO expect high snowfall; PDO should lower for next 20 years; PDO linked with salmon productivity, debris flows (?); PDO is built into management decisions
- Difficult to revegetate disturbed land; park has had mixed results; salvage plant, collect seeds to propagate; turf has been successful
- Mazama ash under surface of soil, bright brown 2 ft thick; when exposed, easily eroded by wind
- Trails that cut through Mazama Ash deposits are deeply eroded (T. Carolin, personal communication, 9/18/02)
- Ash from Mt. St. Helens had a small effect but changed the soil property in the area; Mt. Mazama had a large effect

Stop 5: Sun Point

Topics: site of old hotel, impacts of historic use (horses in high country, backcountry chalets), wind erosion, lichenometry

- Lewis Mtn Overthrust over Cretaceous shale
- Chalet at Sun Point removed in the 1940s
- High winds! (frequency and speed), pebble dunes, pebbles in traps, elimination of fines and creation of armored surfaces, trees flattened
- Lichenometry used for dating debris flows and retreat of glaciers; good standard gotten from vision quest sites

Drive By

- Alluvial fan damming St. Mary Lake (vs. being dammed by terminal moraine), indicator of fan deposits are aspen trees, which don’t grow on well-drained moraines

Stop 6: Divide Creek

Topic: building in floodplain

- 1964 (June 6-8) flooded the entire area; rain on snow event with 12 inches in 24 hours
- Divide Creek bulldozed ½ mile upstream of bridge
- St Mary Resort Lodge built within the last couple of years adjacent to the creek in a low elevation easily flooded by Divide Creek; also park visitor center
- Park has considered moving the entrance station closer to the visitor station and by-pass this area; park doesn’t want to continue maintaining this road section that is continually inundated by floods
- Extreme pressure from landowners of adjacent developments to open the Going-to-the-Sun Road at an earlier date

Stop 7: Chief Mountain Scenic Overlook

Topics: overthrust terranes and Belt Series, oil and gas development, water diversion

- 1992 Helena earthquake caused debris flows and slab-rockfall on the side of Chief Mountain; epicenter near Helena, MT; some stories that rocks made it down to the highway
- Chief Mountain Klippe—remnant of the Lewis thrust on Cretaceous rocks; Lewis Mountain thrust began about 170 million years ago
- Cretaceous shales provide source, and Belt Series provides cap for oil and gas
- 1980s were an exploration period, including thumper trucks
- Potential oil and gas development adjacent to the park; will be a continuous stressor to the park; park has a concern for elk and grizzly migration routes and calving/denning locations
- 15-20 wells under Sherburne Lake—marginal production
- Large water diversion project (1919): canal from Sherburne Lake transport water to the Milk River (tributary to the Missouri River)
- Dominant parent material in the plains is till from Continental Glaciation (Max. 18,000 years old)
- The upland plains surfaces were not glaciated, and half-million-year-old paleosols cap the shales and siltstones, and stabilize the plateau surfaces; slides are associated with groundwater sapping on the bedding planes between the siltstones and shales

Stop 8: Belly River

Topics: Ecological Unit Classification, geological and vegetation maps

- Belly River eventually flows to Hudson Bay
- Extent of continental glaciation—continental glaciers dammed river to create lake (glacial lacustrine deposits/till 12,000 to 18,000 yrs old)
- Vegetation change to deciduous indicates areas of slumping on plateau; lake sediment and tills have greater potential for slope failure
- Ecological Land Classification system widely used in Canada and especially in the mountain national parks. Waterton has 4 ecoregions: (1) Foothills Parkland – pattern of rough fescue grassland and aspen grove forest; (2) Montane – both open and closed coniferous forest, dominated by Douglas Fir and Limber Pine; (3) Subalpine is divided into Lower and Upper; Lower is characterised by closed coniferous forests, especially Engelmann Spruce and Subalpine Fir; Upper is broad zone of open forests and stunted trees, particularly Subalpine Larch and Whitebark Pine; (4) Alpine – treeless region with sparse low vegetation.
- Waterton Lakes only park with Foothills Parkland ecoregion in Canada
- Older geologic map for Waterton Lakes, not comparable with USGS mapping (Paul Carrara)
- Mountain pine beetle infestation caused damage in NE area of the park that killed trees and caused increased slope stability and increased stream turbidity
- Pine beetle attributed to climate change (human element), which has caused a warmer climate that benefits the beetles
- Epidemic run its course and caused high fuel loading and instability
- Need for relatively frequent aerial photography

- 1998 Waterton Lakes flown in cooperation with Glacier NP vegetation mapping
- 2002 Sun Road Corridor aerial photography 1:12,000 by FHA
- Satellite tools for remote sensing
- Current advances with radar, captures centimeter-scale changes—developed for glacier monitoring in Antarctica
- Possible inventory project: lake deposits mapped on Canadian side, not US (Carrara map)

Stop 9: Sofa Mountain Wetland (adjacent to Chief Mountain Highway)

Topics: wetland hydrology, commercial markets

- Waterton Lakes NP has more wetlands than Glacier NP because of extent Continental Glaciation
- Mine sphagnum moss: Von Post Scale of decomposition used to describe sphagnum mosses
- Sphagnum moss with Von Post least scale of decomposition makes the better moss for commercial markets
- Wetlands have hydrologic fluctuations
- No known rate of accumulation and loss—can use air photo interpretation of extent of wetlands
- Highways can impact hydrology and cycles of wetlands
- Sediment cores indicate: rate of sedimentation, change in climate (using pollen data), fire history (using charcoal)
- Paleolimnological techniques such as diatom, ostrocod, chironomid, and cladocera analyses can be undertaken on lake sediment cores to determine limnological processes over time (e.g., productivity, pH, salinity, etc.)

Drive By: drumlin features

Stop 10: Blakiston Valley

Topics: background information and current research on Belt Series

- Over 2,100 meters thick with no gap in sediment record
- 1.4 billion old carbonates
- 50 million years stable basin; therefore, long record
- Amazon size river transport sediment in to belt basin
- Theory: Rodonesia (Queensland, Australia, large mountains like Himalayas) uplifted and shed clastic sediments across Siberian plain
- Research question: Is the depositional environment lacustrine or marine?—look for varves if lake or cycling (tidalites) if ocean; do know that it was a "flat" environment; no shoreline has been found
- Geochemistry data to determine source areas
- Grinell Formation—red coarse sandstone; Appekunny Formation—green finer silts (under water); same mineralogy but grain size difference only; diagenic changes from red to green
- Flame structures in color

Stop 11: Blakiston Fan/Waterton Golf Course

Topics: alluvial fan, park facilities on fan, Holocene fossils, stream channel morphology and flooding

- 1939 photographs (taken from high points) exist; Waterton Lakes has access to original glass plates—good for documenting landscape change
- 1995 flood significantly altered alluvial fan in the area
- 4,000-year-old bison bones found in area
- Sediment cores taken from Waterton Lakes
- Park facilities and golf course built on alluvial fan
- Changing channel of stream flooded road to popular picnic area

Appendix I: Proposal for Soil Carbon Storage Study

Project Description—What is the project all about? Concisely describe what is to be accomplished. Where and when it is to be accomplished. (<2,000 characters)

Soil Carbon Storage—to understand the present levels in appropriate Peace Park life zones (ecoregions) and monitor on approximately 5 year intervals. Measuring the organic carbon in surface soil layer(s) by sampling and resampling at the same locations is required.

Project Justification—Concisely and accurately describe why this project is needed. (± 4,000 characters)

Carbon sequestration by storing carbon in soils and plant material is an important way to reduce overall greenhouse gas content in the atmosphere. Monitoring of organic carbon at appropriate locations is essential to recognize change before the resultant biota community change.

Project Results—What benefits will be gained from completing this project? What quantifiable output will result from this project being completed? Has this project helped the park to achieve a GPRA goal? Also, indicate specifically how park operational efficiency will be enhanced. (± 4,000 characters)

Cost Estimate

Limited resources are needed both in human and in fiscal and could easily be combined with efforts in USA (NRCS) and Canada (Agriculture and Agri-Food Canada, Dr. G.M. Coen, Lethbridge Research Center) and Alberta Public Lands (Barry Adams, 403-382-4299).

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